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THE INTERACTIVE EFFECTS OF CARBON MONOXIDE AND ALCOHOL ON DRIVING SKILLS

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Ohio State University

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THE INTERACTIVE EFFECTS OF CARBON MONOXIDE AND ALCOHOL ON DRIVING SKILLS

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16. Abstracts

This report presents the findings of an investigation of the interactive effects of carbon monoxide and alcohol on driving skills. The objective of the study was to determine the combined effects of carbon monoxide and alcohol (ethanol) on driving performance in normal driving tasks, and to establish "bench marks" of performance and equivalence levels for comparing carboxyhemoglobin combined with carbon monoxide) effects to corresponding blood alcohol effects on driving performance. CO-alcohol interaction was observed to be synergistic (combined effect greater than the sum of individual effects) in driver control measures in curve negotiation tasks at 12% COHb level. Under the test conditions, 0.04% BAL was found to have no interaction effect with COHb or possibly offsetting COHb effects. On the bench mark relations the general conclusion was that 0.04% BAL has even less effect on driver performance than the 8% COHb level.

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PREFACE

This report presents the findings of a one-year investigation of the interactive effects of carbon monoxide and alcohol on driving skills. This study was performed under contract to the Coordinating Research Council.

The scope of this study includes two major objectives:

1. To determine the combined effects of carbon monoxide and alcohol (ETHANOL) on driving performance in normal driving tasks, and
2. To establish "bench marks" of performance and equivalence levels for comparing carboxyhemoglobin (percent of hemoglobin combined with carbon monoxide) effects to corresponding blood alcohol effects on driving performance.

The opinions, findings and conclusions in this publication are those of the authors and not necessarily those of the sponsors.

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SUMMARY

This one-year research investigated the interactive effects of carbon monoxide and alcohol (Ethanol) on highway driving performance. The research was conducted in three phases. In each phase four young college, non-smoking students were tested. In the first two phases, four treatment levels were used, i.e., in Phase 1 the target COHb levels being 2 and 8%, combined with 0 and 0.05% BAL and in Phase 2 the target COHb levels being 8 and 12% each, combined with 0 and 0.05% BAL. In the third phase two treatment levels, namely both COHb level and BAL at zero percent and 12% COHb level with 0.05% BAL were used. The tasks employed were primarily open road driving, car following, sign reading, and curve negotiation.

The results were analyzed for COHb effects, COHb x BAL interaction and bench mark relations. Based on the previous research, the COHb effects on human functions were hypothesized as perceptual narrowing, decreased visual activity, time compression, and distance expansion. The results of COHb effect from this study were in substantial agreement with the earlier work. COHb effects were observed to be significant only in tasks with higher information processing demands such as curve driving, car following, etc.

CO-alcohol interaction was observed to be synergistic (combined effect greater than the sum of individual effects) in driver control measures in curve negotiation tasks at 12% COHb level. In the visual information processing measures, although the results were not statistically significant, they showed consistently antagonistic (combined effect less than the sum of the individual effects) type of CO-alcohol interaction. It was concluded that, under the test conditions, 0.04% BAL will either have no interaction effect with COHb or may even offset COHb effects.

On the bench mark relations the general conclusion was that 0.04% BAL has even less effect on driver performance than the 8% COHb level. In general there was a high correlation between task demands and the observance of subtle COHb effects. CO-alcohol interaction effects may be entirely synergistic if 0.08% BAL or more is combined with CO, using subjects from susceptible populations in night driving.

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CHAPTER 1

RESEARCH OBJECTIVE AND RELATED LITERATURE

1.1 Introduction

The research reported herein represents a summary of a contract with the Coordinating Research Council to investigate the interactive effects of carbon monoxide and alcohol on driving skills. The research extended over a period of fifteen months from October 1972 to December 1973, and was an extension of an earlier project CRC-APRAC CONTRACT-9-69 which investigated the effects of carbon monoxide on humans in the driving task at 0, 7, and 14% COHb levels. The previous study was reported in a report, "An Investigation of Carbon Monoxide on Humans in the Driving Task," January 1973.

1.2 Research Objectives

The major research objectives were:

1. to determine the combined effects of carboxyhemoglobin (COHb) and blood alcohol (BAL) on driving performance in highway driving tasks, and

2. to establish "bench marks" of performance and equivalence levels for comparing carboxyhemoglobin effects to corresponding blood alcohol effects on driving performance.

The first objective was to determine whether the effects of carbon monoxide and alcohol acting in combination produce changes in driving performance greater than either stressor acting alone; i.e., to determine the presence of alcohol-CO synergistic effects and the levels at which they occur.

The second objective was to compare the COHb effect (high COHb, low BAL) relative to BAL effect (low COHb, high BAL) in order to establish an alcohol bench mark.

1.3 Organization of the Report

In order to establish background information helpful in understanding the problem, Chapter 1 reviews literature pertinent to the present research and supplements the review of the earlier report. Chapter 2 discusses the experimental design, the tasks performed by subjects, performance measures considered, and the dependent variables. Also this chapter describes the subject selection, the subject participation, and road testing procedure. Chapter 3 presents the results of experiments on dependent variables in four categories; i.e., vehicle state measures, control measures, perceptual measures, and laboratory measures of performance. Chapter 4 summarizes the results and presents the conclusions.

1.4 Literature Review

Role of CO in Traffic Accidents

Research in this area has indicated that CO by itself may not be a primary cause in vehicle accidents, but the combined effects of CO and other factors such as alcohol, fatigue, etc., may be more detrimental. Some of the recent literature is reviewed here.

Sunshine, et al., (1968) analyzed blood and urine of adults who died in car accidents during a one-year period in Philadelphia and in an 18-month period in Cuyahoga County in Cleveland. They found alcohol frequently and CO less often and drugs rarely. Ury, et al., (1972) found no significant association between CO and Motor Vehicle Accident frequencies in Los Angeles. In a recently completed study on the role of atmospheric CO in vehicle accidents by Yabroff, et al., (1973) at Stanford Research Institute, it is reported that smoking is probably a much more prevalent source of COHb in the blood of drivers than is atmospheric CO. It is also reported that atmospheric CO may somewhat increase the effects of other accident-causing factors such as alcohol, psychological stress, fatigue, or disease.

Baker, et al., (1972) report the presence of a synergistic effect of alcohol and CO leading to death at lower level COHb saturation levels when BAL concentration is high.

There have been efforts to establish the role of CO in traffic accidents. A study by Waller and Thomas (1971) found that blood concentrations greater than 15 percent COHb were rarely found in highway accidents. However, it has still been suggested that low levels of CO, as found in automobile exhaust or cigarette smoke, can impair driving performance. This study found that fatally injured drivers had more evidence of heavy smoking than drivers stopped at the scene of the accidents, but that the "excess was attributed to the fact that heavy smokers also are heavy drinkers." This statement reiterates the importance of determining the combined effects of CO and alcohol on driving performance.

Effects of CO on Human Performance

The literature on the CO effects on human performance have been reviewed and reported in the Final Report of the previous study (Weir and Rockwell, 1973, pages 4-11). Hence only the literature subsequent to the previous study will be reviewed here.

More recent lab studies as reported by Rockwell, et al., (1973) indicated that performance decrements at 20 percent COHb were much more apparent as task difficulty increased. At lower levels (7, 14 percent COHb) no statistically significant effects on reaction times or tracking error scores were found.

The fact that many discrepancies exist in the literature may be due to a number of factors. Rockwell and Ray (1967) mention the fact that earlier reports of the 1940's lacked precise methods of determining COHb levels. They also stated that "in many studies of CO, controls are often lacking to distinguish between objective and subjective results, between time performance decrements and decrements in motivation, or to account for the different sexes, ages, physical condition, and smoking habits of the individuals being tested."

It has been suggested by McFarland (1971) that previous studies have been handicapped by the fact that the subtle effects of low concentrations of CO can be masked by greater exertion. It has also been pointed out by Attwood (1972) that decrements become more apparent as the tasks used to measure performance require more participation of vision and higher mental processes. Therefore, in more demanding situations such as driving, where tasks of different complexities are being performed simultaneously, the decrement could produce disastrous results. It seems then that the detection of CO effects at low levels, if any, hinges in part upon the development of sensitive performance measures.

In a recent study, Wright, et al., (1973) reported that in a test with fifty adults, brake reaction time, night vision, glare vision, glare recovery, head steadiness and depth perception did not significantly deteriorate with 3.5% increase in their COHb level, but the direction of changes was toward poor performance. In the same study it was also reported that during the operation of a driving simulator, the CO exposed group showed a highly significant deficit in "careful driving skills." McFarland (1973) found no significant differences in a number of laboratory tasks involving a complex psychomotor task, dark adaptation, glare recovery, and depth perception under 0, 11, and 17 percent COHb levels. However he did find significant change in the peripheral vision tasks under 17% COHb.

CO Effects on Driving Performance

The literature concerning the effects of low levels of CO on actual driving performance has been lacking until recently. Rockwell and Ray (1967) performed an exploratory study on the effects of 0, 10 and 20 percent COHb on driving performance. Their results indicated that these levels adversely affected such driving performance measures as the ability to detect relative velocity, or estimate distance traveled.

Safford (1971) conducted road research involving the effects of COHb on visual spare capacity, a measure attempting to reflect the amount of information processing capacity available to the driver. He found that CO detracted from this capacity, and that the degradant also affected control behavior necessary to achieve "error free" driving performance.

In a recent study by McFarland (1973) the overall pattern of results indicated that a 6% COHb level had no effect on driving ability and that 11% and 17% did not appear to seriously affect the driving performance. In an occlusion task at 17% COHb level the subjects required relatively more roadway viewing at higher speed (50 MPH) than at low speed (30 MPH). It was also reported that CO does not differentially affect the frequency of steering wheel reversals at 17% COHb.

In the earlier study by Weir and Rockwell (1973), driving performance was categorized into three levels:

visual (perception and information acquisition)
control (psychomotor)
dynamic response (time delayed vehicle response)

It was reported that perceptual measures would be affected most. The trends in perceptual measures were reported in Figure 8.3 on page 120 of the earlier report (Final Report, CRC-APRAC Project CAPM-9-69, 1973). The following were the performance measures affected by COHb from the data of the earlier study:

1. perceptual uncertainty increases
2. spare visual capacity decreases
3. mean time looking straight ahead increases
4. percent of total time straight ahead increases

These results lead to two hypotheses; i.e., perceptual narrowing and decreased visual activity. Perceptual narrowing would suggest a reduction in the variety of visual cues searched. Decreased visual activity would suggest a decrease in information processing rate.

Another performance measure which has been studied is time estimation at elevated COHb levels. Rockwell and Ray (1970) found that with increase in COHb level, there were decreases in the mean and variance of time estimation (time compression). Harshman (1973) also observed a decrease in time estimation at 8% COHb levels. Beard and Wertheimer (1967) also observed this time compression effect of COHb. However, this effect was not observed in many other laboratory studies - Stewart, et al., (1970, 1973), Mikulka (1969), O'Donnell (1971). Studies by Ray (1967) show evidence that in the distance estimation drivers tend to estimate higher at higher COHb levels (distance expansion).

In conclusion, based on the literature on COHb effects on driving performance, the following four hypotheses are derived. Elevated levels of COHb in drivers cause

1. perceptual narrowing
2. decreased visual activity
3. time compression
4. distance expansion

Toxicological Effects of Alcohol

The widely experienced characteristics of alcohol intoxication have been summarized by the A.M.A. (1970). It indicates that alcohol is a depressant which first acts on brain centers responsible for integrating control, with the result of impaired judgment and motor processes as well as behavior alteration. It further states that as intoxication progresses, mental processes developed in learned and experienced skills are affected. The individual begins to acquire a false confidence, and feels he is performing better than he actually is. As the alcohol concentration increases, gross incoordination develops and emotional outbursts may occur. At very high levels the temperature may drop below normal, and the subject may lapse into a coma and die. The lethal dose of alcohol is approximately 5 g/kg (A.M.A., 1970) but this is seldom achieved as deaths from acute alcoholic intoxication are rare. To determine the concentration of alcohol in the brain of a living person, indirect methods must be employed. Analyses of the blood, breath, or urine are the most common means of predicting brain alcohol concentrations.

It is important to mention that the concentration of alcohol in the blood may be expressed in different ways and to point out the relationship between these different methods to avoid misinterpretation. Blood alcohol concentration (BAC) is usually expressed as either an alcohol weight to blood volume ratio (w/v), or an alcohol weight to blood weight ratio (w/w). Medical and related professionals use the w/v method, e.g., "mg/100 ml," or "mg percent." Legalistic terminology utilizes the w/w method, usually expressing it as percent blood alcohol concentration (% BAC) or percent blood alcohol level (% BAL). Since the density of blood is nearly the same as that of water, the two methods are almost equivalent. For example, 50, 100, and 150 mg/100 ml. are equivalent to .05, .09, .14 percent BAL (A.M.A., 1970, p. 67). As long as alcohol level measurements are explicitly reported, no confusion should arise. In this report the notation % BAL will be used.

Role of Alcohol in Traffic Accidents

It is well known that alcohol is involved in an alarmingly large number of road fatalities. In addition, the proportion of traffic deaths associated with alcohol is rising steadily. This percentage was estimated to be about 22 percent in the 1940's, 35 percent in the 1950's, and over 50 percent in the 1960's Bacon (1968).

Many studies have been conducted to attempt establishment of the relationship of alcohol to traffic accidents. A summary of 36 such research efforts conducted between 1936 and 1965 has been presented by the A.M.A. (1970, pp. 36-49). The studies are virtually unanimous in the finding that increased blood alcohol concentrations (BAC's) result in a greater probability of accident involvement. Results presented also showed that driving was impaired at BAC's as low as .04 percent (Borkenstein, 1964; Haddon, et al., 1959; Smith and Popham, 1951; Vamosi, 1961). More recent studies by Zylman (1968), Laessig and Waterworth (1970), and Waller (1972) have not only confirmed the significant role of alcohol in traffic accidents, but have investigated the interaction of alcohol with other factors. All three studies are in agreement that more accidents involving alcohol occur late at night and that the highest frequency of alcohol related accidents occurs among persons in the late teens to early 20's age group. Waller suggests that these young drivers are more susceptible because they are on two learning curves, one for drinking and one for driving. The importance of considering drinking and driving experience in alcohol driving research is reinforced by Zylman who found drinking and driving experience to be inversely associated with accident experience. However, any research efforts utilizing accident data can only lead to inferences about driving performance deterioration.

Lab Studies on Alcohol

There have been numerous studies concerning the effects of alcohol on human performance. Of particular interest are those which have investigated skills closely related to driving. These experiments have been classified by Carpenter (1961) into areas of reaction time (RT), motor skills, positional nystagmus and sensory processes.

RT studies involve simple (same response to a single stimulus) and choice (different responses depending on stimuli presented) reaction time tests. For relatively low blood alcohol levels, little or no impairment was found in simple visual RT (Carpenter, 1959; Lambercier and Martin du Pan, 1946; Howells, 1956). In the complex or choice RT experiments, decrements at lower levels of alcohol have been reported (Gruner, 1955; Gruner and Ptasnik, 1953; Lambercier and Martin du Pan, 1946; Patay, 1956; Rauschke, 1954). Zirkle (1959) found no effect on choice RT, but he considered only very low levels of alcohol.

Studies concerning motor skills have demonstrated that performance is impaired at low BAL's. In reference to the A.M.A. (1970) review of the literature, decrements have been found at levels as low as .02 percent BAL w/v (Bschor,1952). Numerous tests comparing handwriting legibility, time required for writing, fine motor and handwriting skills have shown degraded performance at levels as low as .05 percent BAL w/v.

Nystagmus (involuntary oscillation of the eye) is reported to be the earliest sign of alcohol intoxication (Howells, 1956). It first begins to appear at about .05 percent BAL w/v. Positional alcohol nystagmus (PAN) can be separated into two phases. PAN I occurs during the alcohol ingestion and lasts three to four hours. It consists of fast eye movements to the right when in the right lateral position, or left when in the left lateral position. After one to two hours after cessation of PAN I, PAN II appears and lasts from five to fifteen hours. It consists of motions just opposite of PAN I. PAN II is more intense than PAN I, with both being related to the unpleasant sensations of hangover.

Research investigating the effects of alcohol on sensory processes has been extensive. While other senses have been found to be affected to a smaller degree, the sense of vision by comparison is the most sensitive to alcohol. Experiments involving various aspects of vision all show alcohol has marked effects, and significant findings have been summarized by the A.M.A. (1970, p. 32). Voluntary convergence is impaired at levels as low as .03 percent BAL w/v, and visual acuity losses occur as low as .08 percent BAL w/v. Glare resistance decreases, and critical fusion frequency (CFF) and peripheral fields are affected at low levels. Time to adjust from near to far is affected at .06 percent BAL w/v. These lab studies and others are helpful in ascertaining the effects of alcohol on driving skills, but cannot take the place of driving research.

In a recent symposium on Alcohol, Drugs and Driving, Perrine (1973) after reviewing a number of laboratory studies about alcohol influences on driving-related behavior concludes the following: the Reticular Activating System (RAS), a component of the central nervous system, is largely responsible for performance on tasks involving divided attention and not intensive attention. Also the RAS functions are probably more affected at low BAL's than other aspects of CNS. Hence, performance on tasks involving divided attention is impaired at low BAL's. Perrine also discusses the "biphasic effects of alcohol;" i.e., alcohol is frequently found to have opposite effects at low BAL's than it does at medium or high BAL's, such that low concentrations seem to be excitatory or stimulating whereas higher concentrations result in inhibitory or depressant effects. On the sensory aspects of vision the following are Perrine's conclusions. Impairment in static visual acuity, adaptation and brigntness sensitivity is significant only above 0.08% BAL. Dynamic visual acuity for some is affected at BAL's as low as 0.02%, but for all persons it is impaired at 0.10% BAL. There is no appreciable reduction in the extent of lateral visual field even at high BAL's. Significant impairment in glare resistance and recovery and critical flicker fusion occurs only above 0.08% BAL's.

According to Moskowitz (1973), peripheral vision will be impaired if it is examined while information processing by other channels also takes place. Generally compensatory tracking is affected only at very high BAL's whereas impairment in pursuit tracking could be observed above 0.05 or 0.06 BAL. Time shared or divided attention tasks are impaired at low levels of alcohol.

Driving Research

Driving research can be broken down into two areas: Driving simulation studies, and actual road tests. In general, driving simulation experiments have found impairment due to alcohol levels below .10 percent BAL w/v. Drew, et al., (1958) used steering accuracy as a measure of driving skill and found impairment in all subjects at .08 percent BAL w/v. Hine (1956) tested 300 subjects in a simulated driving device and found performance decrements in all subjects at levels below .10 percent. Loomis and West (1957) found effects due to BAL as low as .05 percent on subjects trained to standard performance in a simulated driving device, while Marquis (1957) using AAA's "Auto Trainer" found no effect of alcohol at levels less than .05 percent. Mortimer (1963) used his own simulator apparatus under normal day and night conditions and found alcohol (.07 percent) significantly increased tracking errors under the night conditions.

More recently Martin (1971) studied the effects of alcohol (.05 and .10 percent) on operator inputs and responses using driving simulation. His results indicated that alcohol at these levels had no significant effect on accelerator reversals, but did affect steering measures. Previous simulation studies have measured driver control maneuvers as a result of information acquired, primarily through the visual mode. Recently, Buikhuisen and Jongman (1972) studied visual perception of a roadway film using a "television eye marker," which records the exact position on the screen where the subject is looking. At levels of .08 percent BAL they found subjects exhibited narrowed visual perception or tunnel vision, and missed much more peripheral information presented in the film than sober subjects. Their results also indicated that sober subjects perceived critical objects sooner, and made more "eye-jumps." Also, the variance of eye-movement patterns for the intoxicated group was smaller, suggesting a "less flexible search pattern."

In the area of road driving research, most of the literature shows driving skill deterioration at less than .05 percent BAL (Carpenter, 1961). Studies by Bjerver and Goldberg (1950), testing the driving ability of thirty-seven expert drivers on a special test track, found blood alcohol levels of .05 percent BAL w/v or less impairs driving of these skilled persons. Coldwell, et al., (1958) used practical road tests and found impairment of driving skill at levels as low as .03 percent BAL w/v. Huber (1955) tested motorcycle riders and found ability to judge speed was impaired at levels below .05 percent BAL w/v. Cohen, et al., (1958) studied risk acceptance of highly experienced bus drivers, and found that they exhibited faulty judgment and overconfidence of their driving skills at levels as low as .04 percent BAL w/v.

Although these studies involved driving a motor vehicle, none actually tested the intoxicated subject in the real road environment. Such studies, along with simulation studies especially, are at a disadvantage. Carpenter (1961) points out that neither permits operation of the vehicle in the actual traffic environment, and that the absence of traffic reduces the hazard of driving and perhaps the accompanying motivation.

A pilot study by Belt (1960) placed the subject in the live highway environment under carefully controlled conditions at levels of 0, .037, .070 percent BAL w/v. Psychomotor tests showed no alcohol effect except for increased velocity variance. In reference to visual measures obtained using an eye-marker camera system, Belt found tunnel vision as well as increased eye fixation durations associated with increased blood alcohol concentrations.

After reviewing a number of driving research studies, Huntley (1973) summarizes that alcohol increases time to complete driving tasks, the number of pylons upset, velocity maintenance variation, the number of driving procedural errors, control response times and control use rates. It also decreases driving smoothness, stopping accuracy, the extent of the visual field explored, and cornering ability. In his conclusions Huntley (1973) stresses the importance of studying visual search behavior of drivers under the influence of alcohol and also the interaction of alcohol with other variables with which it is likely to be combined.

CO, Hypoxia and Alcohol

A review of the literature by Attwood (1972) points out most researchers suggest that the effects of CO are very similar to hypoxia (oxygen deficiency) experienced at high altitudes. Studies by McFarland et al., (1944) and Lilienthal and Fugitt (1946) found a direct correspondence between COHb levels and simulated altitudes, using visual thresholds as performance criterion. Attwood shows their results indicated that a physiological altitude of 7,000 ft. was equivalent to 7 to 8 percent COHb level. Research involving the effects of alcohol and hypoxia, then, may be helpful in formulating hypotheses concerning possible synergistic effects between alcohol and CO, as the literature is lacking in the latter area.

Early studies by Newman (1941) revealed that simulated altitudes of 18,000 ft. brought about reduction of muscular coordination at low levels of alcohol, while no decreases in performance were detected at these altitudes without alcohol. McFarland (1943) found the effects of alcohol intoxication greatly increased with hypoxia. He reported a simulated altitude of 10,000 ft. and .03 percent BAL w/v affected critical fusion frequency (CFF), whereas it was not affected at .03 percent at 0 ft. More recently, research by Mazess (1968) reported a definite synergistic interaction of alcohol and hypoxia on performance during rest and work. The results of all these studies indicate the likelihood of the existence of a synergistic effect of alcohol and hypoxia. It follows then that since CO and hypoxia effects are similar, one would expect definite synergistic effects between CO and alcohol. An attempt will be made to test this hypothesis in the current study, with the hopes of quantifying this relationship, if any, with respect to normal control level performance of the driving task.

Summary

There are over 50,000 traffic fatalities annually in the United States, Bacon (1968). These accidents occur due to a number of different factors which affect the drivers' ability to perform the driving task. There is much evidence showing that alcohol is involved in over 50 percent of these fatalities. Also, it is realistic to assume that alcohol is not the lone cause in many of these accidents, and that it is very likely acting in combination with other variables. One such variable is CO, as studies have indicated the driver may often be exposed to measurable quantities while driving.

Research is needed in the area of the combined effects of CO and alcohol on driving performance. The literature abounds with studies of low blood alcohol effects on human performance in the lab and on the road with many reporting significant decrements below .05 percent BAL. Studies concerning the effects of CO are not in such agreement on the level of COHb at which performance is impaired; some report effects as low as 4 percent, while others can find none until 20 percent COHb. Such discrepencies may have resulted from a lack of precise techniques for determining COHb, or from a lack of precise experimental design and control. Also contributing is the fact that the research findings are a function of the tasks performed.

Most of the research on both alcohol and CO reveals that the visual system shows the first signs of impairment. Since vision plays such an important role in driving, driving research in this area should investigate visual measures as a function of the contaminants, along with other psychomotor measures.

CHAPTER 2

RESEARCH DESIGN AND METHODOLOGY

This chapter consists of details of the experimental design for the research, the task description and the dependent variables considered, road research equipment, subjects, and experimental procedures.

2.1 Experimental Design

The experiments were carried out in three phases. Phases 1 and 2 were four level Latin Square Design and Phase 3 was a straight two-way classification model.

Phase 1: The three factors for the 4x4 Latin Square were subjects, days, and treatments. Each of the factors was used at four levels. Four treatment levels were obtained by combining the two BAL levels (0, 0.05) and the two nominal COHb levels (2 and 8 percent).

Phase 2: Phase 2 was similar to Phase 1 with differences only in COHb levels; i.e., COHb levels used were 8 and 12 percent levels.

In both Phases 1 and 2 each of the respective four subjects were tested on four different days with a different level of treatment on each day.

Phase 3: In Phase 3, the subject factor was at four levels and days at two levels. The two treatments used were 0 BAL, 2 percent nominal COHb and 0.05 BAL, 12 percent nominal COHb. In this phase each of the four subjects were tested on two days with different treatments on each day.

Figure 2.1 shows the designs of all the three phases with the different treatment levels used in each phase.

The twelve subjects are coded as S1, S2, ..., S12.

The four days for each subject in Phases 1 and 2 are coded as D1, D2, D3, and D4. The two days in Phase 3 are coded as D1 and D2.

The six treatments are coded as T1, T2, ..., T6.

The models for statistical analysis for all the three phases are shown in Appendix A.

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Phase 1

	D1	D2	D3	D4
S1	T1	T2	T4	T3
S2	T2	T1	T3	T4
S3	T3	T4	T1	T2
S4	T4	T3	T2	T1

Nominal COHb Level

	2%	8%
0 BAL	T1	T2
0.05 BAL	T3	T4

Phase 2

	D1	D2	D3	D4
S5	T5	T4	T6	T2
S6	T2	T6	T4	T5
S7	T4	T5	T2	T6
S8	T6	T2	T5	T4

Nominal COHb Level

	8%	12%
0 BAL	T2	T5
0.05 BAL	T4	T6

Phase 3

	D1	D2
S9	T1	T6
S10	T6	T1
S11	T1	T6
S12	T1	T6

0 BAL 2% COHb	0.05 BAL 12% COHb
T1	T6

Figure 2.1 - Experimental Design for the Three Phases

2.2 Tasks - Road Tests

Tasks in this research were chosen to reflect different aspects of the driving task felt necessary for safe driving behavior. In addition, certain tasks attempted to utilize as much of the driver's attention as possible, in hopes that such demanding task performance would be sensitive to the low levels of degrandants beind used. This strategy stems from the fact that the normal driving task alone does not fully utilize the information processing capacity of the driver. Therefore, under stressful conditions, there may be not enough spare capacity available for maintaining adequate performance. However, in an emergency situation where the total information processing capacity might be a necessity, these subtle stressor effects could result in performance deterioration.

Such a philosophy has grown out of results from past studies, and has been used effectively by other driving researchers. Attwood (1972) used the dual task approach to find effects due to CO which were not apparent when tasks were performed independently. Safford (1971) attempted to directly measure spare information processing capacity in terms of visual input. He developed an occlusion task which required the driver to close his eyes as much as possible while driving. By monitoring the driver's visual behavior during the task, inferences from measures such as occlusion time (amount of time the eyes are closed) could be made concerning spare visual capacity. The promising results from these studies prompted the use of the following seven tasks in the present research.

Task 1 (T1) - Velocity and time estimation
Task 2 (T2) - Open-road driving with voluntary visual occlusion
Task 3 (T3) - Open-road driving on curves
Task 4 (T4) - Car following with voluntary visual occlusion
Task 5 (T5) - Open-road driving with normal vision
Task 6 (T6) - Car following with normal vision
Task 7 (T7) - Normal driving involving visual sign-reading behavior

A note of explanation is in order concerning these tasks. T1 utilized a dual task approach by requiring the subject to estimate both the length of a given time interval and the velocity maintained during that interval while driving. Tasks labeled as open-road driving (T2, T3, T5) were defined as those requiring that the lane ahead of the research automobile be clear of any vehicles for at least 300 feet. It was felt that in most cases any vehicles beyond 200 feet would not significantly alter the driver's visual sampling behavior. Such an assumption was necessary in light of the fact that the tests were conducted in the live highway environment where other vehicles could interfere. Whenever possible, however, the open road tasks were carried out under open road conditions. Car following tasks (T4, T6) required that the subject maintain an elected distance (headway) from the lead vehicle as well as possible. The voluntary visual occlusion tasks (T2, T4) required the subject to drive and maintain control of the automobile while closing (occluding) his eyes as much as possible. Tasks referred to as normal vision tasks (T5, T6, and T7) were those in which the driver's normal visual sampling behavior was obtained while wearing the eye-marker system. Lastly, T7 required the subject to drive in his normal manner and exit at specified freeway exits so that the sign reading behavior of the subject could be recorded using the eye movement system. As indicated previously, the selection of these particular tasks was influenced by previous research, in hopes of providing new insights as well as investigating CO and alcohol effects. The instruction used during the road test for all the tasks are given in Appendix B.

2.3 Dependent Variables

The dependent variables which were obtained from the various tasks are listed below.

1. Time estimation error: (sec.) (Task 1 only)
2. Velocity estimation error: (MPH) (Task 1 only)
3. Headway: Mean, standard deviation (ft.) (Tasks 4 and 6)
4. Steering wheel reversals: (Number/min.) (Tasks 3 & 5)
5. Peak lateral acceleration in g's (Task 3)
6. Velocity reduction in curves (Task 3)
7. Mean, SD,* and percent of total of open and closed times (Tasks 2 & 4)
8. Open road task visual behavior measures: (object code analysis) (Tasks 5 & 6)
9. Signing task visual behavior measures: Total time on sign, etc.) (Task 7)

While most of these dependent variables are fairly straightforward, the visual occlusion task measures mentioned above warrant additional explanation. The visual occlusion task measures, first introduced by Safford (1971), involved performance criterion attempting to quantify the amount of spare visual capacity available to the driver under the different conditions. These included measuring the amount of visual information felt necessary (percent of time the driver kept his eyes open and obtained visual information) and unnecessary (percent of time closed without seeking information) to maintain lateral and longitudinal control of the vehicle. The average (mean) and variability (standard deviation) of these visual occlusion measures were also considered. The visual behavior measures associated with the normal open road and car following tasks were obtained from the video-taped-eye-movement data. The object code analysis of this data consisted of partitioning the road scene into sectors defined by various object codes, and then investigating both temporal and spatial behavior of the eye fixations in terms of these codes (see Appendix C). Lastly, the signing task visual behavior measures also utilized eye movement data in an attempt to characterize the sign reading behavior of the subjects as a function of the degradant levels. The variables chosen to describe such behavior closely correspond to those used in earlier signing research by Bhise (1972). The reader is referred to more complete discussions concerning these measures under the appropriate headings in the following analysis chapter.

2.4 Road Research Equipment

Road research equipment used may be categorized into apparatus used for obtaining driving measures and apparatus used to monitor and maintain COHb and BAL levels.

---

*SD denotes standard deviation.

Driving Equipment:

Equipment used for collecting road performance data consisted of two vehicles. One vehicle, a 1965 Plymouth station wagon was used merely as a lead vehicle in car-following tasks. The instrumented vehicle in which the subject, safety man, and experimenter rode was a 1970 Chrysler Newport. It was a four-door sedan with automatic transmission, power steering, power disc brakes, and a 440 cubic inch V-8 engine. An auxiliary brake pedal was installed for use by the safety man who rode as a front seat passenger. The vehicle was modified by the Systems Research Group to enable the operation of two complete data collection systems while in the driving mode (see Figure 2. 2).

Oscillograph System:

This system consisted of a set of mechanical and electrical sensors whose signals were recorded by a Honeywell Oscillograph Recorder Model Number 2206, thus being recorded on photosensitive oscillograph paper. The traces recorded included distance pulses, velocity, lateral acceleration, steering wheel movement, brake pedal activation, gas pedal activation, and a stimulus signal for facilitating data reduction.

Television Eye Movement System:

The Television Eye-Movement System used in this research was developed by the Systems Research Group (see Figure 2. 3). Basically, it consists of a closed circuit television system within the car in which all video input is recorded on video tape, for later playback and analysis in the lab. The unique characteristic of the eye-marker system is that it allows a spot of light (eyespot) corresponding to the driver's foveal fixation to be superimposed upon the driver's view of the road ahead while he is actually driving. Except for a helmet modification in which a set of adjustable pads replaced the individual polyurethane helmet liner, the system used in this research was the same as that used and described by Safford (1972, pp. 235-238). The recorded picture consists of the driver's view of the road which contains the superimposed eye spot, along with a view of the driver's eye, and digital distance and time readouts for reduction purposes. For a more complete description, the reader is referred to Rockwell, Bhise, and Mourant (1972).

Equipment to Monitor BAL and COHb Level:

The equipment used to monitor and maintain BAL and COHb concentration in the field was set up in a room at the OSU airport. Choosing this location allowed the subject to be "refreshed" at 45 to 60 minute intervals while on the road. The equipment used at this "refreshment" center utilized breath samples for determination of both BAL and COHb level. A Borkenstein Breathalyzer was

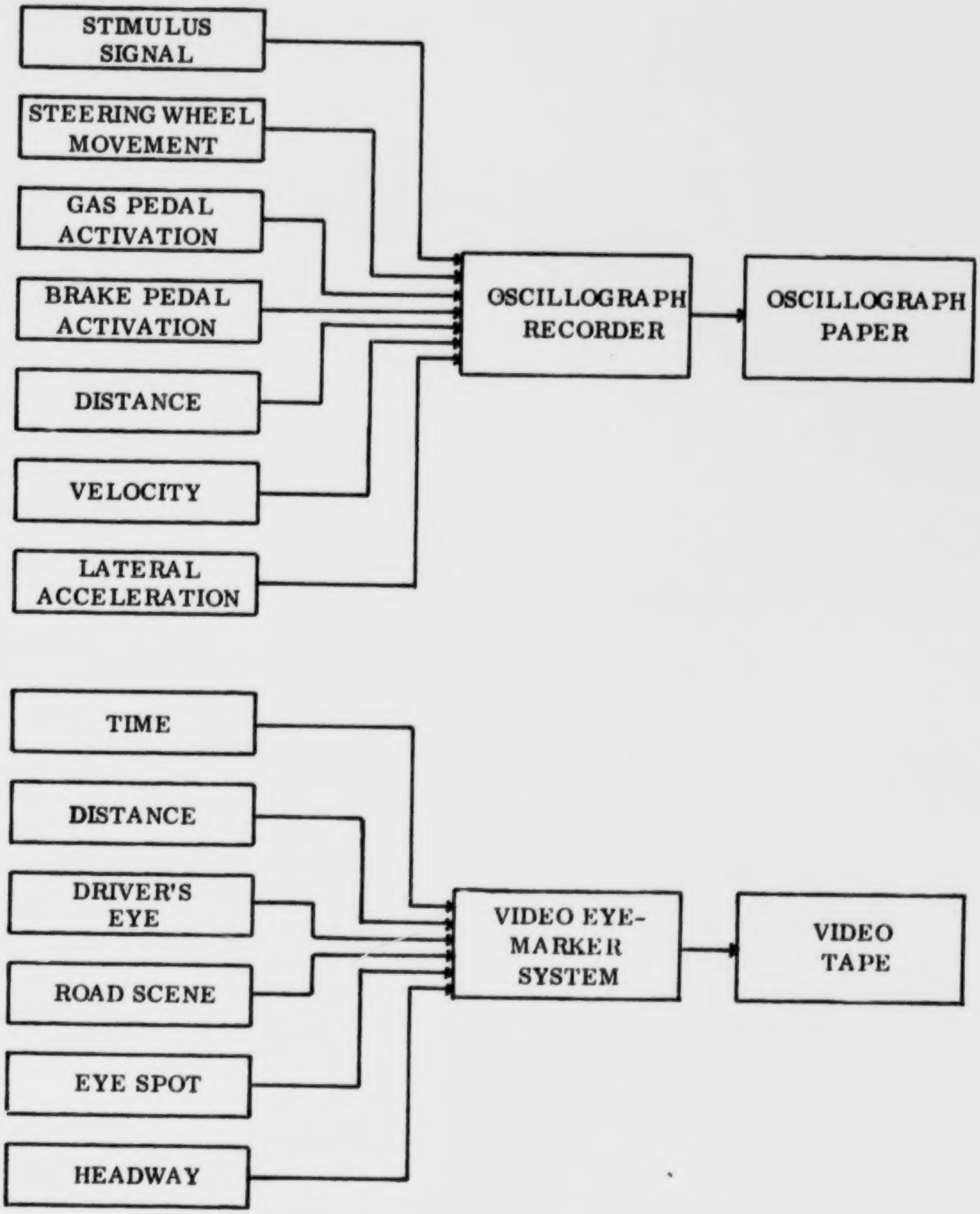

STIMULUS SIGNAL
STEERING WHEEL MOVEMENT
GAS PEDAL ACTIVATION
BRAKE PEDAL ACTIVATION
DISTANCE
VELOCITY
LATERAL ACCELERATION
OSCILLOGRAPH RECORDER
OSCILLOGRAPH PAPER
TIME
DISTANCE
DRIVER'S EYE
ROAD SCENE
EYE SPOT
HEADWAY
VIDEO EYE-MARKER SYSTEM
VIDEO TAPE

Figure 2. 2. --Instrumented Vehicle Data Collection System

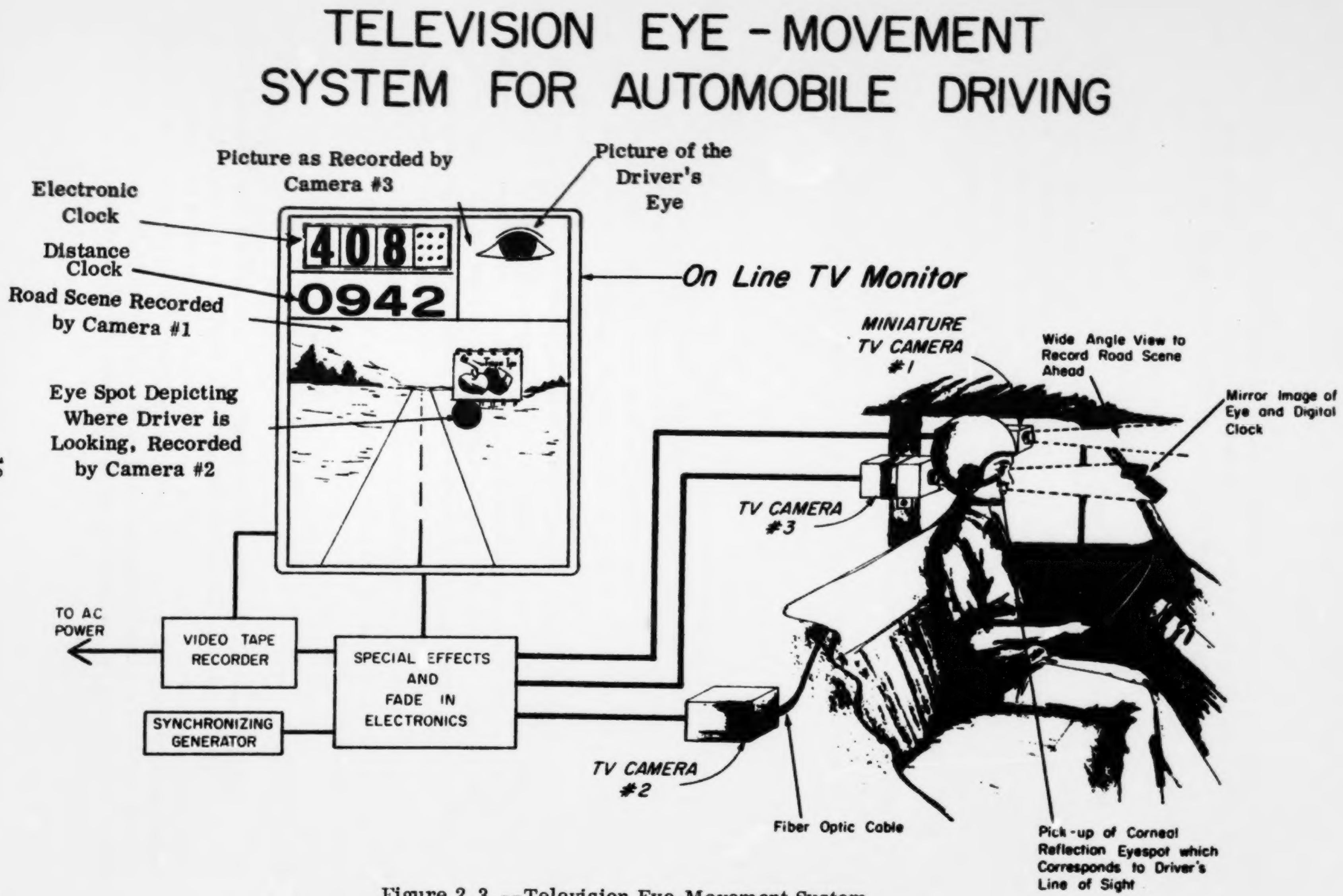

TELEVISION EYE - MOVEMENT SYSTEM FOR AUTOMOBILE DRIVING
Picture as Recorded by Camera #3
Picture of the Driver's Eye
Electronic Clock
Distance Clock
Road Scene Recorded by Camera #1
Eye Spot Depicting Where Driver is Looking, Recorded by Camera #2
408
0942
On Line TV Monitor
MINIATURE TV CAMERA #1
Wide Angle View to Record Road Scene Ahead
Mirror Image of Eye and Digital Clock
TV CAMERA #3
TO AC POWER
VIDEO TAPE RECORDER
SPECIAL EFFECTS AND FADE IN ELECTRONICS
SYNCHRONIZING GENERATOR
TV CAMERA #2
Fiber Optic Cable
Pick-up of Corneal Reflection Eyespot which Corresponds to Driver's Line of Sight

Figure 2. 3. --Television Eye-Movement System
(Source: Rockwell, Bhise, and Mourant, 1972)

used for alcohol concentration readings, and a Beckman Infrared Analyzer, Model 215B, was used for determination of COHb levels. The relationship between the concentration of CO in breath and COHb level had previously been determined in the lab.

To maintain the correct level of intoxication, the proper amount of CO and/or alcohol would then be administered, the amount being dependent on the readings previously obtained. CO was administered using a mask and demand regulator from a pressure cylinder, with the quantity measured through a Parkinson Cowan dry gas meter. Cylinders used for this purpose contained 0 or 1, 000 ppm CO in air. The zero ppm cylinder was used on control days. Alcohol was administered orally with orange juice. Orange juice without alcohol was given on control days.

Blood samples were taken during the refresh stop for later, more accurate analysis of COHb and BAL at the preventive medicine laboratory. The breath alcohol method was compared to the GC method used in the lab.

2.5 Lab Equipment

All subjects were brought to the desired COHb level before road testing by a two-hour exposure to the proper concentration of CO in an exposure chamber. The procedures used and the chamber are described by Rockwell, et al., (1973). One-half hour before the time the subjects were to complete the chamber exposure they were given alcohol mixed with orange juice, the amount determined was dependent on body weight (0.56 gr. EtOH/kg. body weight) (Sidel, 1971; Sollmann, 1957; and Idestrom, 1968). While in the chamber and on the road, capillary blood samples were taken routinely for chemical analysis of COHb and BAL. The COHb determinations were performed using a Beckman Acta-II spectrophotometer using a modification of the technique used by Commins and Lawther (1965), Buchwald (1969) and Rockwell and Weir (1973). BAL determinations were performed on a Hewlett Packard Model 700 gas chromatograph (Curry, 1966). A column packed with Porpack S^R was used instead of the packing described. When the subject had completed the road tests, detoxification involved breathing oxygen by mask to reduce COHb levels, while alcohol metabolized naturally.

2.6 Subjects

Subjects used in this study were healthy college students over the age of 21, with valid driver's licenses and considerable driving experience. All subjects had uncorrected vision and were non-smokers. All claimed at least occasional drinking and some admitted to occasional driving after drinking. Each subject completed a health questionnaire and consent form (Appendix D), and was required to undergo a complete physical examination by a physician before final acceptance.

2.7 Research Personnel

For the experimentation conducted on the road, three experimenters were necessary. One person drove the lead vehicle in the car-following task, and assisted the principal researcher in calibrating the eye-marker system.

The other two experimenters rode with the subject in the instrumented vehicle as he performed the driving. The experimenter who sat as passenger in the front seat was a member of the Preventive Medicine Group and acted as the safety man while on the road. The safety man could observe the subject at all times and use the auxiliary brake if the situation demanded. He also performed all the necessary functions at the "refreshment" site. This consisted of monitoring and maintaining proper COHb levels and BAL's, taking capillary blood samples, and checking physiological signs such as pulse and blood pressure to assure subject health and safety.

The road researcher rode in the back seat of the instrumented vehicle and controlled all the equipment used in recording the various driving performance measures. It was his responsibility to set up the eye-marker apparatus and to ensure that all sensors were calibrated correctly.

2.8 Experimental Procedures

Figure 2.4 presents a graph showing the approximate intervals at which COHb and BAL measurements were obtained both in the lab and on the road during a typical subject session. Included are the two "refresh" stops during which the necessary CO or alcohol was administered to maintain the proper intoxication levels, using the methods and equipment described earlier. The graph also shows typical COHb and BAL levels as a function of time, reflecting the necessity of these "refresh" stops.

The route over which subjects were tested consisted almost entirely of freeway driving, with one task being on a rural road. Tasks 1 and 7 were performed on state route I-71 between Hudson Street and I-270, while tasks 2, 4, 5, and 6 were tested on route I-270 between I-71 and Sawmill Road. The only task not involving freeway driving was task 3, which covered approximately four miles on state route 315 (see Figure 2.5).

Once at the proper level, the subject left the chamber and was asked to fill in a questionnaire in which information regarding any feelings of headache, drowsiness, etc., were recorded. Then the subject drove the research vehicle to the starting point of task 1. At all times throughout the study, the safety man and principal researchers rode as passengers in the vehicle. At the beginning of task 1 as well as the rest of the tasks, the subject listened to tape recorded

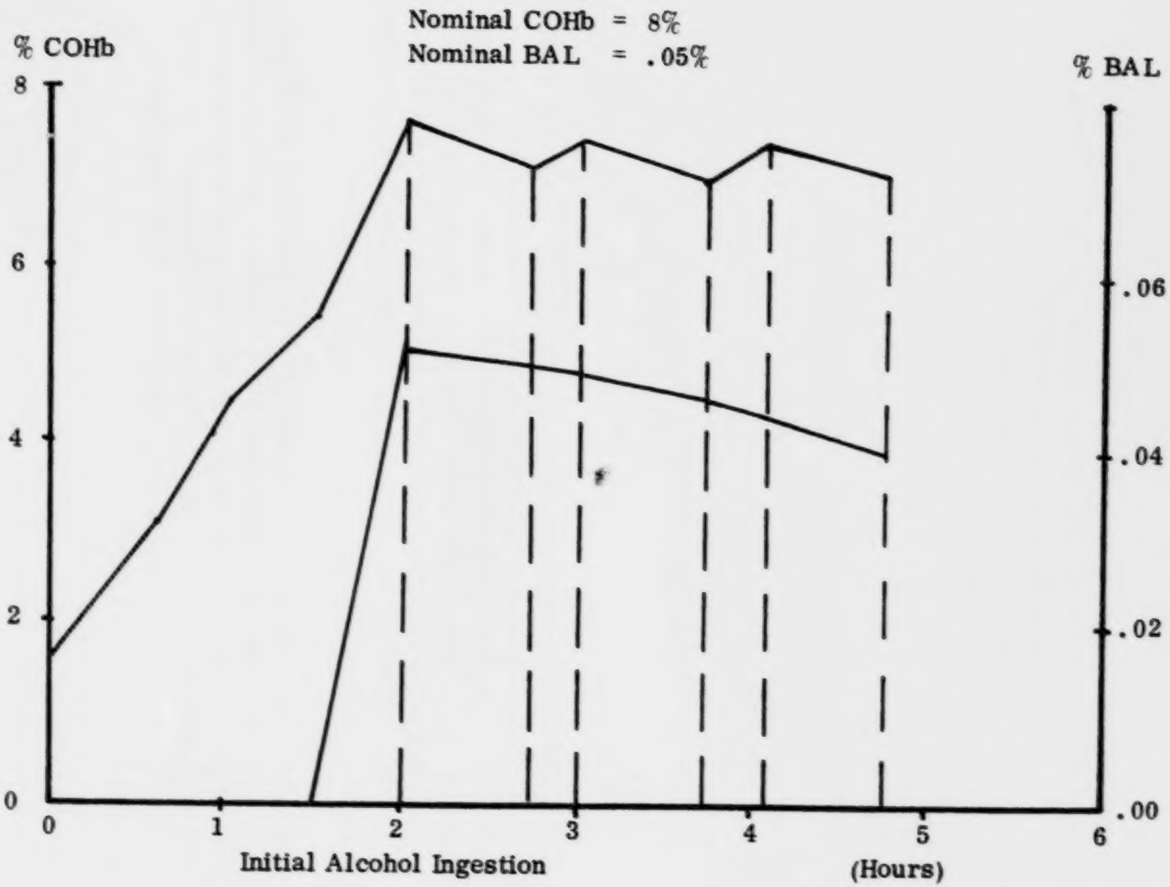
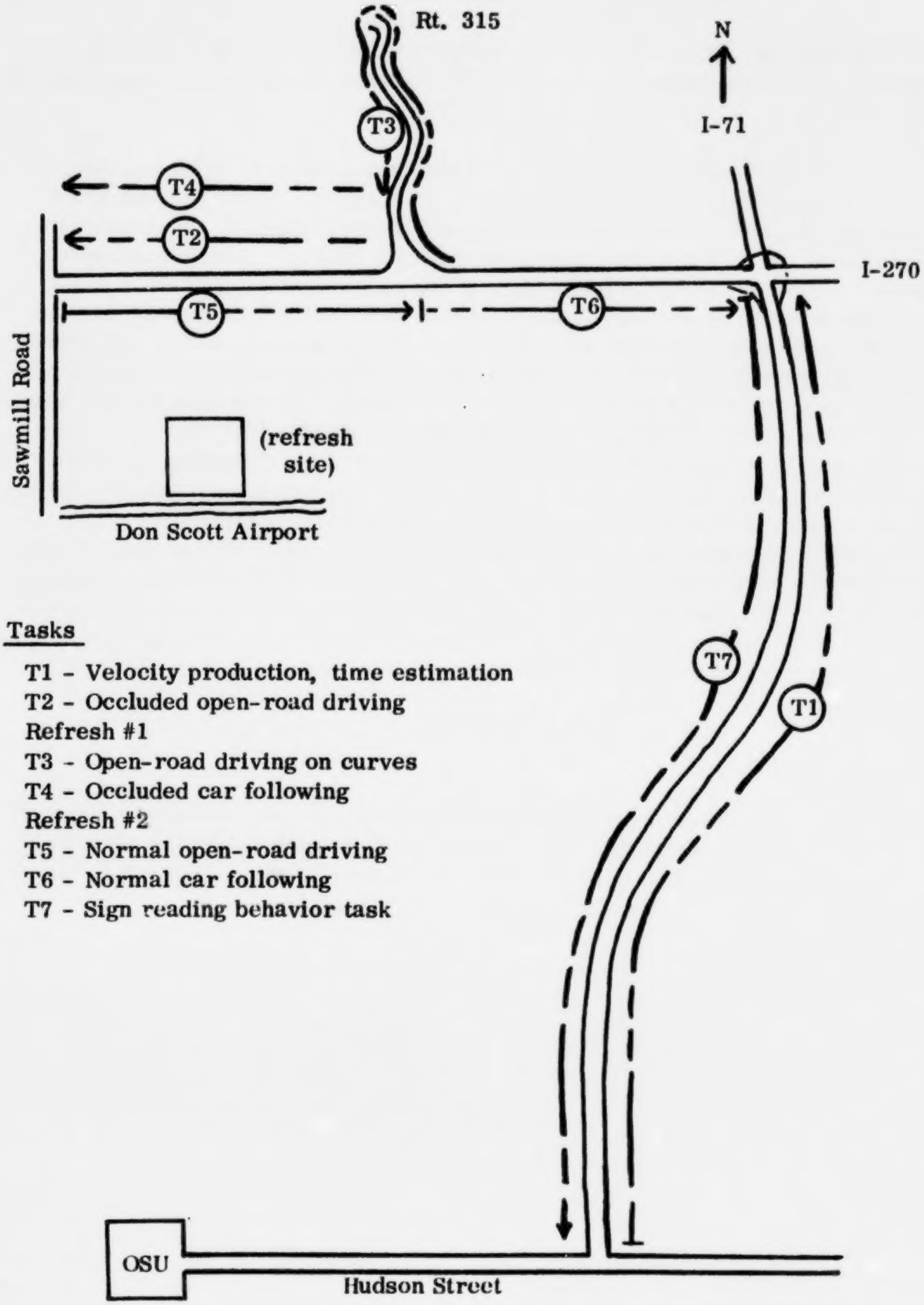


Figure 2.4.--Graph Depicting COHb and BAL versus Time


Rt. 315
N
I-71
I-270
T1
T2
T3
T4
T5
T6
T7
Sawmill Road
(refresh site)
Don Scott Airport
OSU
Hudson Street

Tasks

T1 - Velocity production, time estimation
T2 - Occluded open-road driving
Refresh #1
T3 - Open-road driving on curves
T4 - Occluded car following
Refresh #2
T5 - Normal open-road driving
T6 - Normal car following
T7 - Sign reading behavior task

Figure 2.5.--Map of Route (not to scale) task instructions. Instructions were recorded to assure that each subject received exactly the same instructions, thus helping to remove any experimenter bias.

After performing tasks 1 and 2, which lasted about 45 to 60 minutes, the subject drove to the "refreshement site" at the airport. Here, the necessary equipment had been established for the appropriate physiological procedures discussed earlier. After the subject had been "refreshed" (which took approximately 15 minutes) he drove the portion of the route completing tasks 3 and 4, which again lasted approximately 45 to 60 minutes. After this second "refresh" stop, the eye-movement apparatus was set on the subject's head and calibrated. Then while the subject drove from the airport to the starting point of task 5, a dynamic calibration was performed to ensure the eyespot accurately corresponded to the driver's view of objects on the road ahead. On this last leg of the route, the eye-marker system recorded tasks 5, 6, and 7, with the subject exiting finally at Hudson Street. At this time the helmet apparatus was removed and the subject returned to the Preventive Medicine Laboratory, where he was then detoxified by breathing oxygen intermittently for one hour. The total road expermentation for each session thus lasted appr ximately 2 1/2 to 3 hours. Throughout the research the experiments were performed "double blind", i. e., neither the subject nor the researcher who collected the data knew about the treatment levels. The actual values of COHb levels and BAL's of the subjects during each run is given in Appendix E.

2.9 Laboratory Tests

Laboratory tests were carried out to investigate the interactive effects of CO and alcohol on performance in tests such as Spatial Relations, Mirror Tracing, Brightness Discrimination, and Rail Walk. The design for the tests and the results from the analysis are given in Appendix G.

CHAPTER 3

RESULTS

This chapter presents the approach given to the analyses of data and the results. The results are presented in the following four categories:

1. Driver control and vehicle state measures.
2. Visual spare capacity measures.
3. Visual behavior measures. (Open road driving and car following).
4. Visual sign reading behavior measures.

3.1 Approach to Data Analyses

The first step in the analyses was to identify trends in the dependent variables due to CO, alcohol and CO-alcohol interaction. A trend was assumed to exist based on the practical significance of the difference between two treatment averages. For example, in the headway measures a difference of ten feet will be considered as practically significant. In the visual spare capacity measures and visual behavior measures a difference of 0.1 second was considered to be practically significant. The second step was to determine the statistical significance of the above trends. The different models used in the statistical analysis are described in Appendix A. An effect was said to be statistically significant if the p values were less than or equal to 0.1. However, when stating the results the exact p values are reported so that the reader can draw his own conclusions about statistical significance (if the effect was significant). The third step was to determine the nature of CO-alcohol interaction; i.e., to determine whether or not CO-alcohol interaction leads to the presence of 'synergism' or 'antagonism'. Synergism means that the combined effect of CO and alcohol is greater than the sum of the effects of CO and alcohol taken individually. Antagonism means that the combined effect is less than the sum of the individual effects. The fourth step in the analyses was to investigate the alcohol-CO bench mark. This was done by comparing the effect of HIGH BAL, LOW CO with that of HIGH CO, LOW BAL. The above steps are represented schematically in Figure 3.1.

3.1.1 The Effects and their Terminology

In order to understand the results of this study, it is necessary for the reader to be familiar with the following concepts and their terminology related to the main and interactive effects of CO and alcohol.

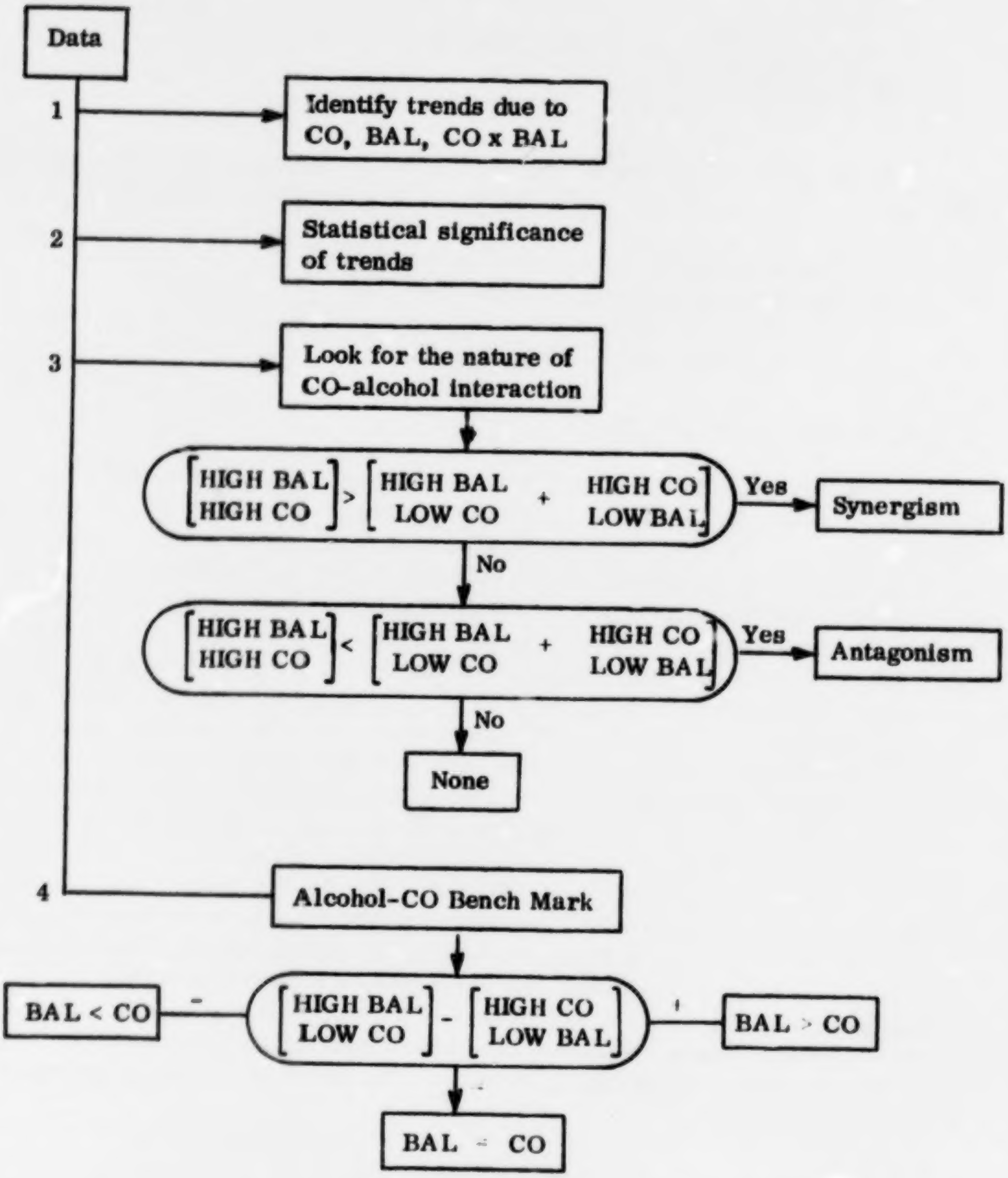

Data
1
Identify trends due to CO, BAL, CO x BAL
2
Statistical significance of trends
3
Look for the nature of CO-alcohol interaction
HIGH BAL HIGH CO > HIGH BAL LOW CO + HIGH CO LOW BAL
Yes
Synergism
No
HIGH BAL HIGH CO < HIGH BAL LOW CO + HIGH CO LOW BAL
Yes
Antagonism
No
None
4
Alcohol-CO Bench Mark
HIGH BAL LOW CO - HIGH CO LOW BAL
-
BAL < CO
+
BAL > CO
BAL = CO

Figure 3. 1. --Schematic Diagram Showing Data Analysis Approach

3.1.2 COHb Effect

In Phase 1, the COHb effect represents the effect due to 8% COHb when compared to the effect of 0% COHb. This can be expressed in terms of the notation of Figure 3.2 as

$$(P_2 + P_4) - (P_1 + P_3)$$

In Phase 2, a similar expression for the COHb effect may be written as

$$(Q_2 + Q_4) - (Q_1 + Q_3)$$

Here the COHb effect refers to the effect of 12% COHb when compared to the effect of 8% COHb.

		Nominal COHb		
		0%	8%	12%
BAL	0% (Lo)	R_1, P_1	P_2, Q_1	Q_2
	0.05% (Hi)	P_3	P_4, Q_3	Q_4, R_2

NOTE: P's represent the four treatment averages in Phase 1
Q's represent the four treatment averages in Phase 2
R's represent the two treatment averages in Phase 3
(Each of the P's, Q 's and R's is the average of the data points for four subjects).

P_2 is the average under 0% BAL, 8% COHb, in Phase 1
Q_3 is the average under 0.05% BAL, 8% COHb, in Phase 2
R_2 is the average under 0.05% BAL, 12% COHb in Phase 3
(Similarly, the other averages can be identified with their respective treatment conditions and phases).

Figure 3.2.--Arrangement of Data Points under the Six Treatment Conditions and Three Phases of Experiments

Based on the nature of COHb effects in Phases 1 and 2, they may be considered to represent the following types of effects. (See Figure 3.3).

Figures 3.3a and b are indicative of threshold effects where 'a' represents an early effect due to CO and 'b' represents late effect due to CO. Figure 3.3c indicates an additive effect when CO is said to be affecting the performance continuously in the same direction. Figure 3.3d is called adaptation effect. This can be explained in terms of initial degradation in performance and a subsequent compensation by the driver. At this point the reader should note that the two data points of 8% COHb level may not coincide in all the measures due to the fact that these two points represent the average conditions of two different groups of subjects from two experiments. Trends other than the four explained can be attributed to phenomena requiring future research.

3.1.3 BAL Effect

BAL effect in general refers to the effect of 0.05% BAL when compared to the effect of 0% BAL condition. In Phase 1, as per Figure 3.2, this can be expressed as

$$(P_3 + P_4) - (P_1 + P_2)$$

and in Phase 2, this can be expressed as

$$(Q_3 + Q_4) - (Q_1 + Q_2)$$

3.1.4 Interactive Effects

The main question that is being answered under interactive effects is whether or not an interaction that is observed is synergistic or antagonistic in its effect. By definition, synergism means the combined effect is greater than the sum of individual effects. Antagonism means the combined effect is less than the sum of the individual effects.

No Interaction

In the context of this research the case of no interaction can be expressed as follows:

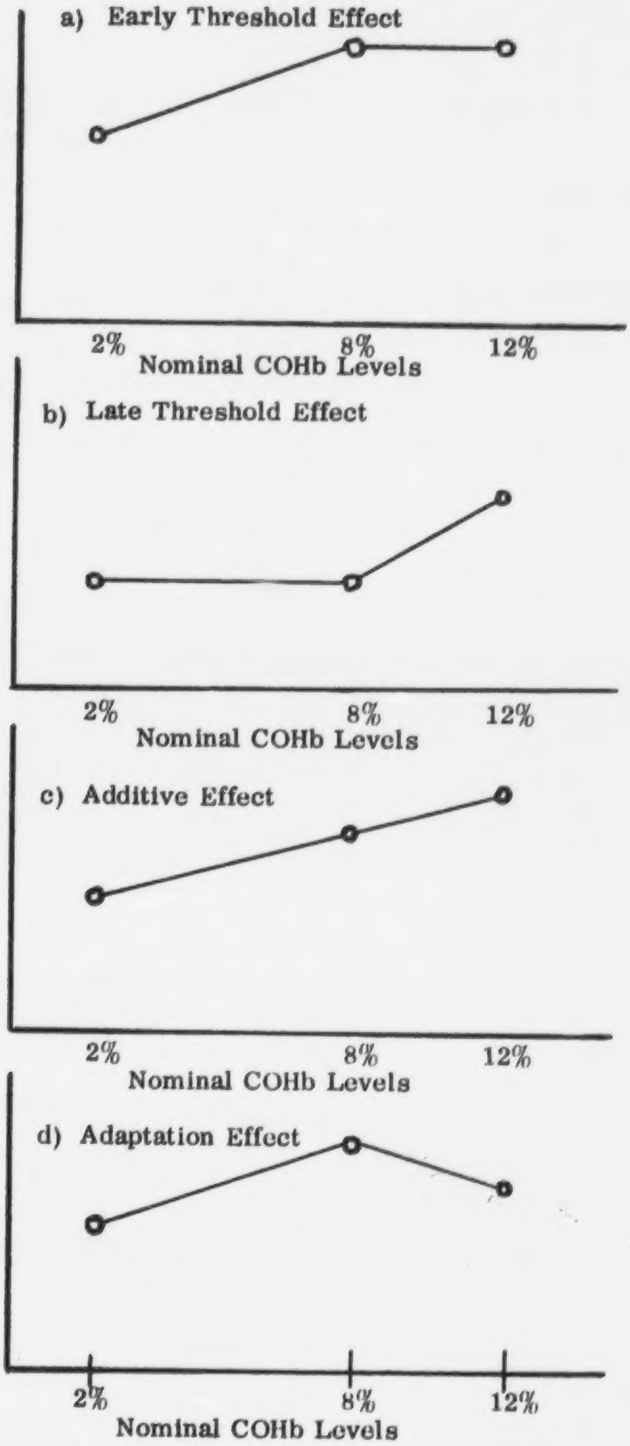


Figure 3. 3.-- COHb Effects (Concepts)

Let Δ_1 be the effect due to BAL alone compared to the control condition $(P_3 - P_1)$
Let Δ_2 be the effect due to CO alone compared to the control condition $(P_2 - P_1)$
Let Δ_3 be the effect due to interactions of CO and alcohol compared to the control condition $(P_4 - P_1)$

Then for the case of no interaction, by definition

$$\Delta_3 = \Delta_1 + \Delta_2$$

Using the notation of Figure 3.2 this can be written as

$$(P_4 - P_1) = (P_3 - P_1) + (P_2 - P_1) \text{ for Phase 1}$$

or $$(P_1 - P_1) + (P_4 - P_1) = (P_3 - P_1) + (P_2 - P_1)$$

or $$(P_1 + P_4) = (P_3 + P_2)$$

Similarly for the no interaction case in Phase 2 the expression can be written as

$$(Q_1 + Q_4) = (Q_3 + Q_2)$$

Synergism

In the context of this research if synergism exists,

$$\Delta_3 > \Delta_1 + \Delta_2$$

By the similar arguments of the earlier section, this can be written as

$$(P_1 + P_4) > (P_2 + P_3) \text{ in Phase 1}$$

and $$(Q_1 + Q_4) > (Q_2 + Q_3) \text{ in Phase 2}$$

Antagonism

If the interaction is one of antagonistic in nature, then

$$\Delta_3 < \Delta_1 + \Delta_2$$

or $$(P_1 + P_4) < (P_2 + P_3) \text{ in Phase 1}$$

and $$(Q_1 + Q_4) < (Q_2 + Q_3) \text{ in Phase 2}$$

It can be seen that the expressions in terms of treatment averages (P's and Q's) are contrasts for interaction and can be used in the statistical analysis of the results. The expression in terms of Δ's (Delta's) are useful in understanding the nature of the interaction from the graphs as shown in Figure 3.4.

3.1.5 Bench-Mark Relations

The point of interest in the bench-mark relations is to determine the magnitude difference between the pure CO effect and pure alcohol effect. Referring to Figure 3.4, Δ_1 refers to the pure BAL effect and Δ_2 refers to the pure CO effect. If $\Delta_1 - \Delta_2$ is positive, then the BAL effect is greater than the CO effect. If it is negative, then the CO effect is greater than the BAL effect. In terms of the notation of Figure 3.2, the expression $\Delta_1 - \Delta_2$ can be written as

$$(P_3 - P_1) - (P_2 - P_1)$$

or

$$(P_3 - P_2)$$

and as such can be used as a contrast for statistical analysis of bench-mark relations.

3.2 Results from Data Analysis

In the analyses to follow, certain performance measures will not be reported because there were no practically or statistically significant treatment effects, other than subject effects. These involved time estimation, velocity estimation, velocity and velocity variance, and gas pedal operation. Only those measures that showed some significance are reported below.

3.2.1 Driver Control and Vehicle State Measures

The dependent variables considered in this category were steering wheel reversals per minute (SWR) from open road driving (Task 5) and SWR per minute, peak lateral acceleration, and velocity reduction while negotiating curves (Task 3), and headway mean and standard deviation from car following tasks (Tasks 4 and 6).

3.2.2 Steering Wheel Reversals

Steering wheel reversals per minute were obtained from two minute samples covering the same stretches of road for Tasks 5 and 3. Reversals were defined as observable (approximately 5° or more) directional-changes

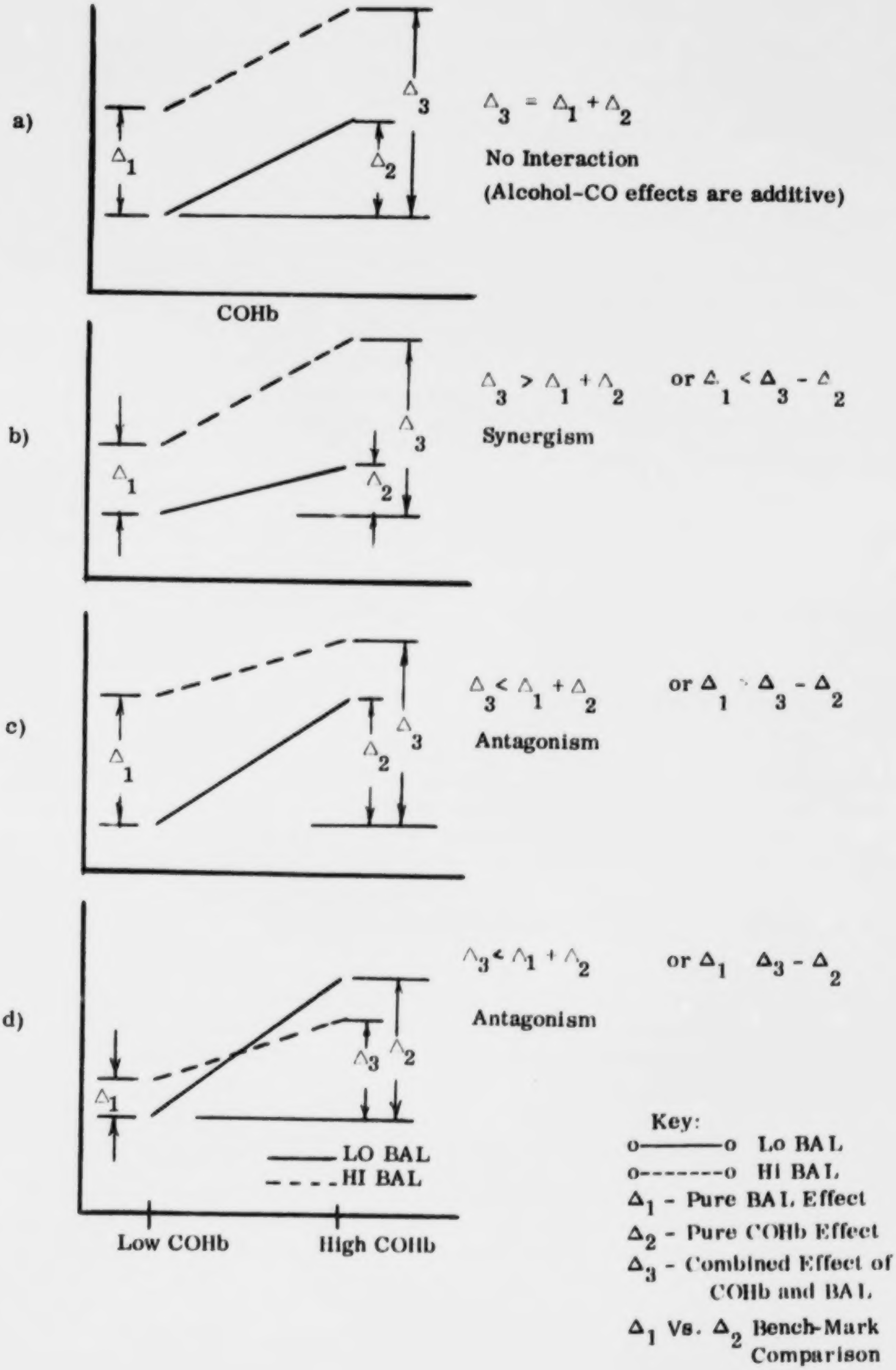

a)
Δ_1
Δ_2
Δ_3
COHb
$\Delta_3 = \Delta_1 + \Delta_2$
No Interaction
(Alcohol-CO effects are additive)
b)
Δ_1
Δ_2
Δ_3
$\Delta_3 > \Delta_1 + \Delta_2$ or $\Delta_1 < \Delta_3 - \Delta_2$
Synergism
c)
Δ_1
Δ_2
Δ_3
$\Delta_3 < \Delta_1 + \Delta_2$ or $\Delta_1 > \Delta_3 - \Delta_2$
Antagonism
d)
Δ_1
Δ_3
Δ_2
$\Delta_3 < \Delta_1 + \Delta_2$ or $\Delta_1 \quad \Delta_3 - \Delta_2$
Antagonism
LO BAL
HI BAL
Low COHb
High COHb
Key:
o———o Lo BAL
o-------o HI BAL
Δ_1 - Pure BAL Effect
Δ_2 - Pure COHb Effect
Δ_3 - Combined Effect of COHb and BAL
Δ_1 Vs. Δ_2 Bench-Mark Comparison

Figure 3.4. -- Interactive Effects of CO and Alcohol

in driver control movements of the steering wheel. The results of analyses of SWR rates are given in Table 3.1.

Open Road Driving:

It is seen from the analysis of data from open road driving that SWR rate initially increases with 8% COHb and later shows a decrement with 12% COHb indicating the presence of some human adaptation property explained in Section 3.1.1. The SWR rate showed a significant* ($p \leq 0.07$) increase with the 12% COHb, HI BAL conditions when compared with the 2% COHb, LO BAL condition.

Curve Negotiation:

In the curve negotiation study SWR rate increases significantly ($p \leq 0.05$) with 8% COHb and no change is observed with COHb level increasing from 8% to 12% indicating the early effect of CO. The CO-alcohol interaction is significant ($p \leq 0.09$) when HI BAL combines with 8% and 12% COHb.

Referring to Figure 3.5, it can be seen that the combined interaction effect of HI BAL at the 12% COHb level is greater than the sum of the COHb effect from 8% to 12% at LO BAL and the HI BAL effect at 8% COHb. Hence, the interaction in Phase 2 is synergistic.

Figures 3.5a and 3.5b show the SWR rates for open road driving and curve negotiation as functions of the three nominal COHb levels for the two levels of alcohol. Higher values of SWR rates observed in curve negotiation can be attributed to the task difference between driving in an open straight road and in curves.

3.2.3 Peak Lateral Acceleration in Curves

The peak lateral acceleration in the eight rural curves was measured in g's. A summary of results on this measure is reported in Table 3.1. Peak lateral acceleration in curves was insensitive to COHb levels and BAL. However, a combination of 12% COHb level and HI BAL significantly ($p = 0.07$) increased the peak lateral 'g' compared to the sum of the individual effects of 12% COHb level and 0.05% BAL. Hence, the interaction is synergistic.

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*Throughout this section the term significant is used to refer statistical significance ($p < 0.1$).

Table 3.1

Summary of Results--Driver Control Measures

1. Trends and Significance

Task	Measure	Phase 1			Phase 2			Phase 3
		8% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb with. 05% BAL
Open Road Driving(T5)	SWR	+	N	-(8% COHb with HI BAL)	-	N	N	+*
Curve Negotiation (T3)	SWR	+*	N	N	N	N	+*(12% COHb with HI BAL)	N
	Peak Lat. Accel.	N	N	-(8% COHb with HI BAL)	N	N	+*(12% COHb with HI BAL)	N
	Vel. Red	N	N	N	N	-*	N	-*

2. Interaction and Bench Mark

Task	Measure	Nature of Interaction		Bench Mark	
		Phase 1	Phase 2	Phase 1	Phase 2
Open Road (T5)	SWR(T5)	N	N	BAL<CO	BAL≈CO
Curve Negotiation (T3)	SWR(T3)	N	S	BAL<CO	BAL<CO
	Peak Lat. Acc. (T3)	A	S	BAL>CO	BAL≈CO
	Vel. Red. (T3)	N	N	BAL≈CO	BAL<CO

N no trend
+ increasing trend
- decreasing trend
≈ approximately equal

* significant (p<.10)
S synergism
A antagonism

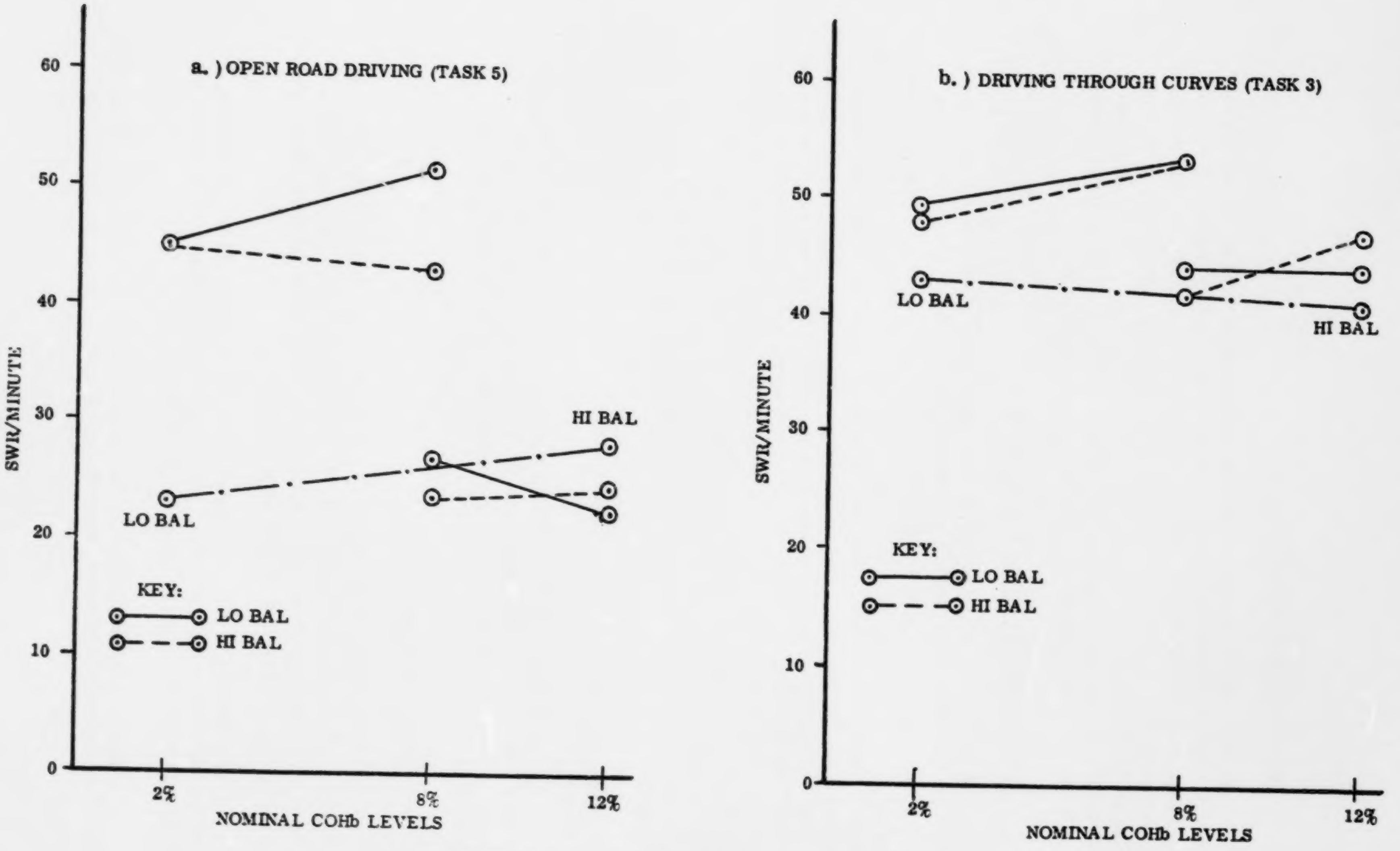

Figure 3.5. -- Steering Wheel Reversals/Minute vs. Nominal COHb Levels

3.2.4 Velocity Reduction in Curves

Velocity reduction in curves was calculated in mph as the difference between the instantaneous velocity when entering a curve and velocity associated with peak lateral acceleration. The results of analysis on this measure is summarized in Table 3.1. Velocity reduction was significantly ($p \le 0.05$) reduced by HI BAL in the range of 8 - 12% COHb levels. But the observed decrement in velocity reduction was of the order of one-half to three-fourths of a mile per hour which may not be practically significant.

3.2.5 Vehicle State Measures (Headway)

In the vehicle state measures the mean and standard deviation of headway from car following with normal vision and car following with occluded vision were considered. Normal vision refers to the non-occluded condition of vision. The headway measurements were obtained from the video recorded picture of the lead vehicle, using the relation of the width of the lead car on the television screen to the actual headway. This relationship was established by static measurements and is shown by the static calibration curve in Appendix F. The headway was sampled every two seconds for one minute of data, yielding 30 data points per run. From these data points, a mean and standard deviation were obtained. Summary of results from headway measures are given in Table 3.2. Based on the method of headway measurement a minimum difference of 10-15 feet between two conditions was considered for determination of trends.

Car Following - Normal Vision (T6)

In car following with normal vision there was no trend in mean headway due to CO alone. The decrease in mean headway with 12% COHb, HI BAL conditions was significant ($p \le 0.07$) when compared with 2% COHb, LO BAL conditions.

Car Following - Occluded Vision

In car following with voluntary occlusion it was observed that CO had a late effect causing significant ($p < 0.01$) reduction in mean headway when COHb level increased from 8% to 12%. In the above range mean headway was significantly ($p < 0.01$) less due to BAL effect.

With respect to S.D. of headway CO had an early effect, increasing the S.D. at 8% COHb level. Alcohol interacting with 8% COHb level produced an antagonistic effect reducing the S.D. of headway.

Figures 3.6a and 3.6b show the mean headway during car following with normal vision and occluded vision as a function of the three nominal COHb

Table 3.2

Summary of Results--Vehicle State Measures

1. Trends and Significance

	Task	Measure	Phase 1			Phase 2			Phase 3
			8% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb with .05 % BAL
Car Following	Normal Vision	Mean Head-way (T6)	N	+	+(8% COHb with HI BAL	N	N	-(12% COHb with HI BAL)	-*(12% COHb with HI BAL)
		S. D. Head-way (T6)	N	+	N	N	N	N	N
	Occluded Vision	Mean Head-way (T4)	N	N	N	-*	-*	N	N
		S. D. Head-way (T4)	+	N	-(8% COHb with HI BAL)	N	N	N	N

2. Interaction and Bench Mark

Task	Measure	Nature of Interaction		Bench Mark	
		Phase 1	Phase 2	Phase 1	Phase 2
C. F. Normal Vision	Mean Headway(T6)	S	A	BAL≈CO	BAL > CO
	S. D. Headway(T6)	N	N	BAL > CO	BAL≈CO
C. F. Occluded Vision	Mean Headway (T4)	N	N	BAL≈CO	BAL < CO
	S. D. Headway(T4)	A	N	BAL < CO	BAL≈CO

Key:
- + increasing trend
- - decreasing trend
- * statistically significant ($p < .10$)
- N no trend
- S Synergism
- A Antagonism
- ≈ approximately equal

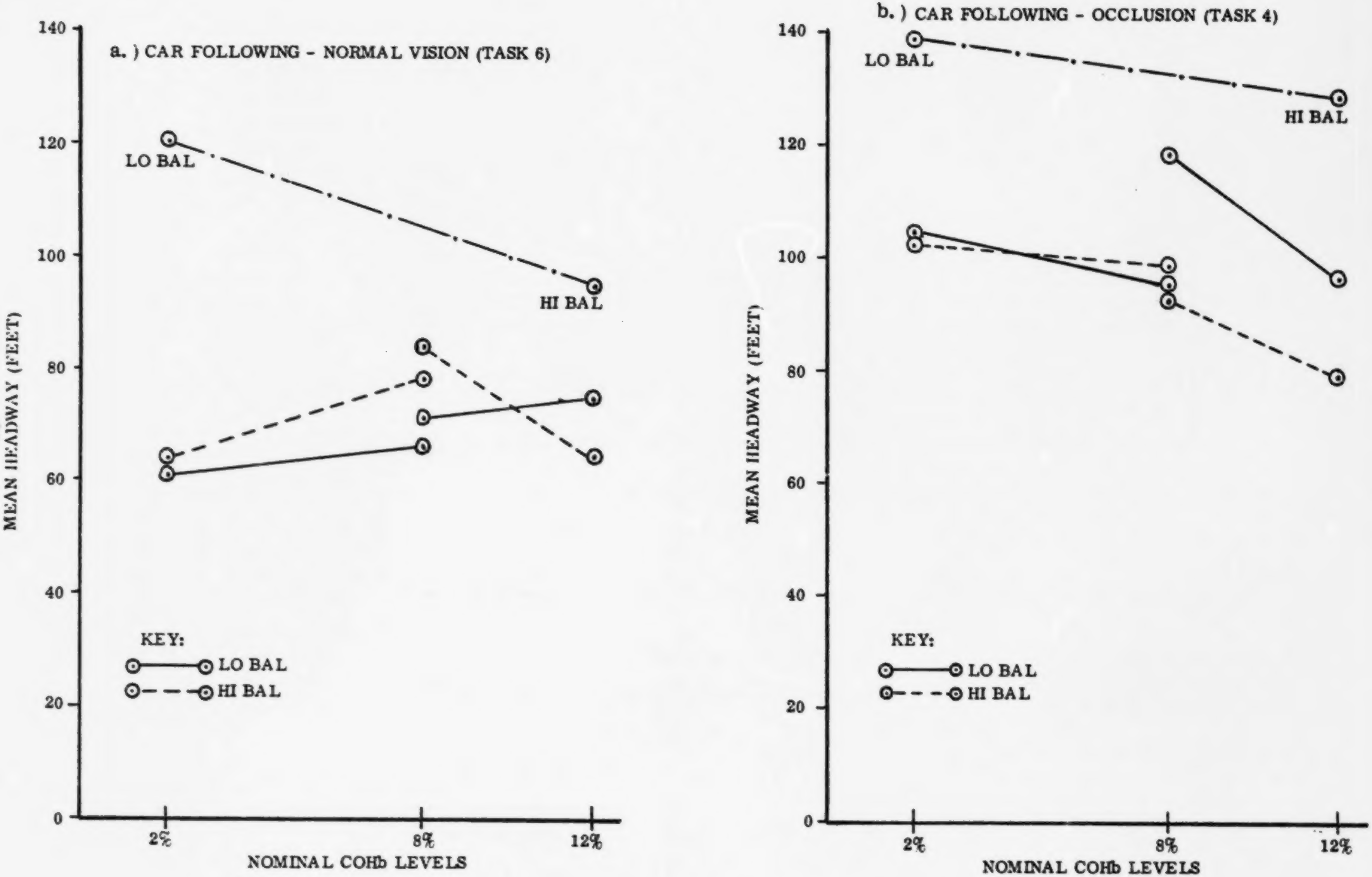

Figure 3.6. -- Mean Headway (Feet) vs. Nominal COHb Levels

levels at various levels of alcohol. Higher values of mean observed in the car following with occluded vision could be attributed to the task difference.

3.3 Visual Spare Capacity Measures

Visual spare capacity measures were obtained from tasks with voluntary visual occlusion; i.e., Task 2 - open road driving with occlusion and Task 4 - car following with occlusion. The primary measures considered were mean and S.D. of "open times," mean and S.D. of "closed times," and percentage of "closed time" to the "total run time." For example, mean open time was the average of all the time intervals during which the subject would keep his eyes open seeking visual information in the occlusion task. S.D. of open time represented the variability of the "open time" intervals. The percentage of "closed times" represented the percentage of total task time the subject would keep his eyes closed (occluded) and drive without visual information. The results for these measures are summarized in Table 3.3a and 3.3b.

3.3.1 Open Road Driving with Occlusion

COHb Effect:

In the open road driving with occlusion the mean open time and S.D. of open time showed an increasing trend with 8% COHb level. However, such trends were not observed in the 8-12% COHb level range.

The mean closed time and S.D. of closed time was significant ($p = 0.01$ and $p = 0.08$) at the 8% COHb level. From 8% to 12% COHb level there was no significant change in the COHb effect.

In general, there was an early CO effect in the above four measures. The increase in both mean open time and mean closed time indicates that with the 8% COHb level there were fewer cycles of opening and closing.

BAL Effect:

The BAL effect was significant with respect to the mean closed time in both the phases. However, in Phase 1 the result was surprising in the sense that the BAL effect significantly ($p = 0.05$) reduced the mean closed time and in Phase 2 it significantly ($p = 0.06$) increased the mean closed time.

Interaction Effect:

There were two significant interactions: The S.D. of open time ($p = 0.075$) in the 8-12% COHb level range and the mean closed time ($p < 0.025$) in the 0-8% COHb level range.

Table 3. 3a

Summary of Results -- Visual Spare Capacity Measures

1. Trend and Significance

		Phase 1			Phase 2			Phase 3
Task	Measure	8% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb, .05% BAL
Open Road Driving with Occlusion (T2)	Mean Open Time	+	-	- with 8% COHb, HI BAL	N	N	+ with 12% COHb, HI BAL	+*
	S. D. Open Time	+	-	- with 8% COHb, HI BAL	-	N	+* with 12% COHb, HI BAL	+*
	Mean Closed Time	+*	-*	-* with 8% COHb, HI BAL	+	+*	N	+*
	S. D. Closed Time	+*	N	- with 8% COHb, HI BAL	N	+	N	+*
	% Closed Time	N	N	N	N	N	N	N
Car Following with Occlusion (T4)	Mean Open Time	N	N	+ with 8% COHb, HI BAL	+	N	+ with 8% COHb, HI BAL	+*
	S. D. Open Time	-	N	+ with 8% COHb, HI BAL	N	N	+ with 8% COHb, HI BAL	N
	Mean Closed Time	+	-	N	+*	+	N	N
	S. D. Closed Time	N	N	N	+	N	- with HI BAL, 12% COHb	+
	% Closed Time	+	N	- with 8% COHb, HI BAL	N	N	+* with HI BAL, HI CO	N

+ increasing trend
- decreasing trend
* significant (p < .1)
N no trend

Table 3. 3b

Summary of Results -- Visual Spare Capacity Measures

2. Interaction and Bench Mark

Task	Measure	Nature of Interaction		Bench Mark	
		Phase 1	Phase 2	Phase 1	Phase 2
Open Road Occlusion (T2)	Mean Open Time	A	S	BAL < CO	BAL < CO
	S. D. Open Time	A	S	BAL < CO	BAL > CO
	Mean Closed Time	A	N	BAL < CO	BAL > CO
	S. D. Closed Time	A	N	BAL < CO	BAL > CO
	Percent Time Closed	N	N	BAL ≈ CO	BAL ≈ CO
Car Following Occlusion (T2)	Mean Open Time	S	A	BAL ≈ CO	BAL ≈ CO
	S. D. Open Time	S	A	BAL > CO	BAL > CO
	Mean Closed Time	N	N	BAL < CO	BAL ≈ CO
	S. D. Closed Time	N	A	BAL < CO	BAL < CO
	Percent Time Closed	A	S	BAL > CO	BAL ≈ CO

N No trend
S Synergism
A Antagonism
≈ approximately equal

The S.D. of open time due to the combined effect of 12% COHb level and 0.05% BAL was greater than the sum of the effect of 0.05% BAL and 12% COHb level when compared with the effect of 0% BAL and 8% COHb level. Hence, the interaction was synergistic in nature.

The mean time closed due to the interaction of 8% COHb level and 0.05% BAL was less than the sum of the individual effects due to 8% COHb level and .05% BAL and hence the interaction was antagonistic in nature. (See Figure 3.4d)

The results of Phase 3 showed that all the four measures discussed in this section showed significant increase due to combined effect of 12% COHb and .05% BAL when compared with the no stress condition.

A closer look at the performance measures in Table 3.3a and b under open road driving with voluntary occlusion will indicate the following: There is an early CO effect and with the inclusion of alcohol this effect is suppressed at the 8% COHb level and accentuated at the 12% COHb level, suggesting that the interaction of alcohol with lower levels of COHb is antagonistic and with higher levels of COHb is synergistic.

3.3.2 Car Following with Occlusion

COHb Effect:

In the car following with occlusion, the only measure that was significantly affected was the mean closed time. The mean closed time showed a 'late CO effect'; i.e., it increased significantly ($p < 0.1$) with 12% COHb level when compared with 8% COHb level.

BAL Effect:

Referring to Figure 3.8 it can be seen that in the 0-8% COHb level range, alcohol reduces the mean closed time and in the 8-12% COHb level range, alcohol increases the mean closed time. Alcohol by itself did not have a significant effect on the spare visual capacity measures in car following with occlusion.

Interaction Effects:

Significant interaction effect was observed in the percent of total time closed in the 8-12% COHb level range. The percent of total time closed significantly ($p < 0.025$) increased due to the interaction of 12% COHb level and 0.05% BAL compared to the sum of the individual effects due to 12% COHb level and 0.05% BAL. Hence, the interaction is synergistic in nature.

Figures 3.7 and 3.8 show the mean of open times and closed times from open road driving and car following as a function of the three nominal COHb levels at various levels of alcohol. It can be seen from the above figures that the values of mean open time and mean closed time for open road driving with occlusion and car following with occlusion were approximately the same. In other words the spare visual capacity measures were not affected by the presence of a lead car. On the other hand, the mean open time for both open road driving and car following was consistently less than the mean closed time indicating some form of threshold to spare visual capacity. Figures 3.9a and b graph the S.D. of open times and closed time from open road driving as a function of the three nominal COHb levels at two levels of alcohol.

3.3.3 Perceptual Uncertainty

An interesting measure first introduced by Rockwell, et al., (1973) was that of perceptual uncertainty. It was obtained from the occlusion tasks T2 and T4 by dividing the mean open time by the percent closed measure and multiplying by 1000. In that study, it was found that this measure increased due to 8 percent COHb, reflecting a "lack of perceptual confidence." Perceptual uncertainty was investigated further to determine the added effect alcohol might have.

Referring to Figure 3.10, it is seen that in the open road driving perceptual uncertainty shows an early increase due to COHb effect. Phase 3 results indicate that CO-alcohol interaction increases the perceptual uncertainty significantly ($p < 0.01$) when compared with control conditions.

3.4 Visual Behavior - Object Code Analyses

Reduction of the eye-movement data obtained from the open road driving and car following tasks (T5 and T6) involved performing an object code analysis, mentioned previously in Chapter 2 and in Appendix C. One object code of particular interest from T5 was that defined as FE (focus of expansion), which encompassed a 3° x 6° block located at the center of the visual road scene. From observed visual behavior and movement of the eye-spot on the televised road scene, it was felt that larger amounts of time spent in this block were a reflection of more concentration focused on the immediate roadway and less visual activity. This measure in particular was devised for the purpose of investigating the effects of CO and alcohol on visual activity, and the lack of such activity (tunnel vision), as detected by Belt (1969). This variable was expressed in terms of the mean, standard deviation, and percentage of the time spent looking in this FE code for each experimental run.

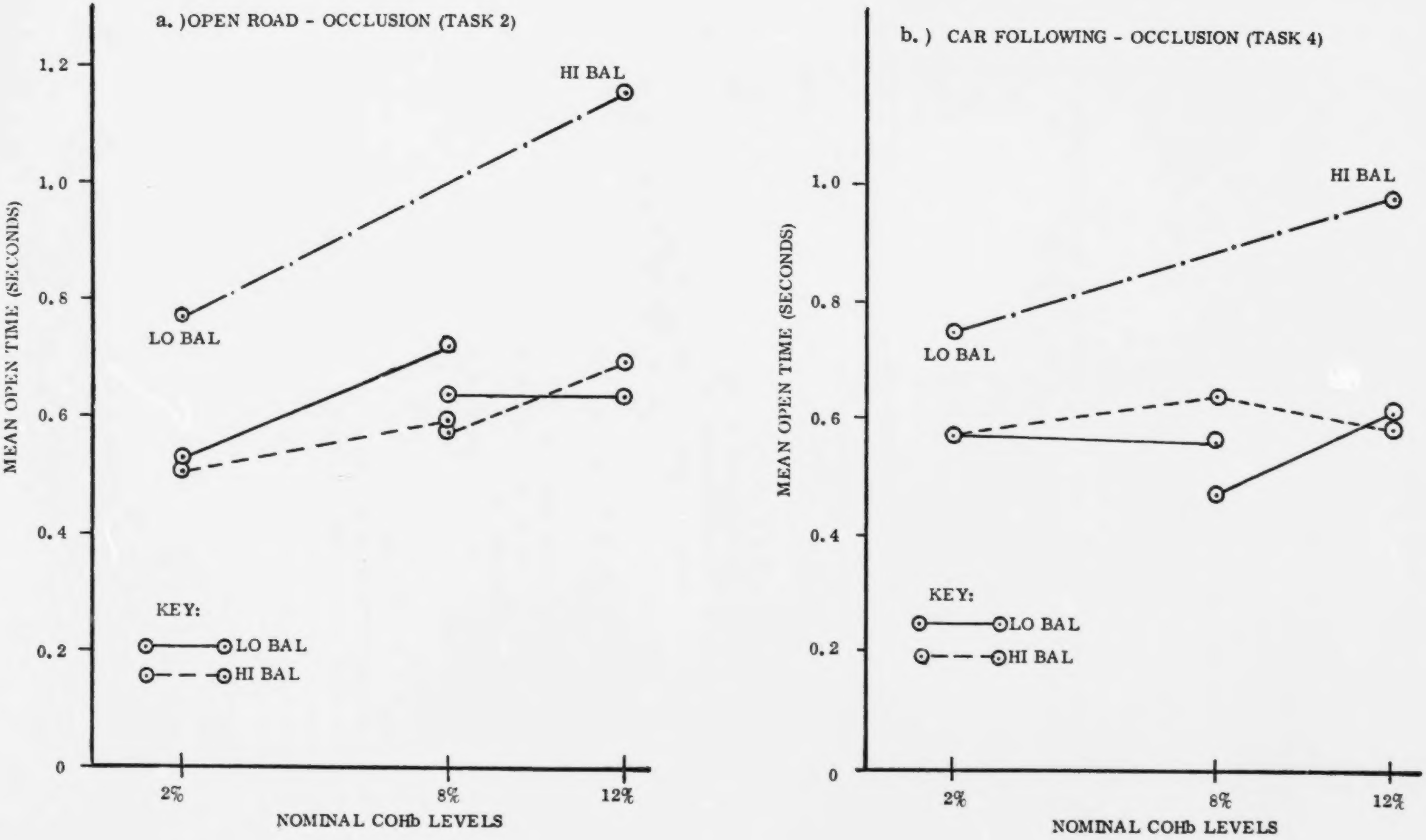

Figure 3.7. -- Mean Open Time (Seconds) vs. Nominal COHb Level

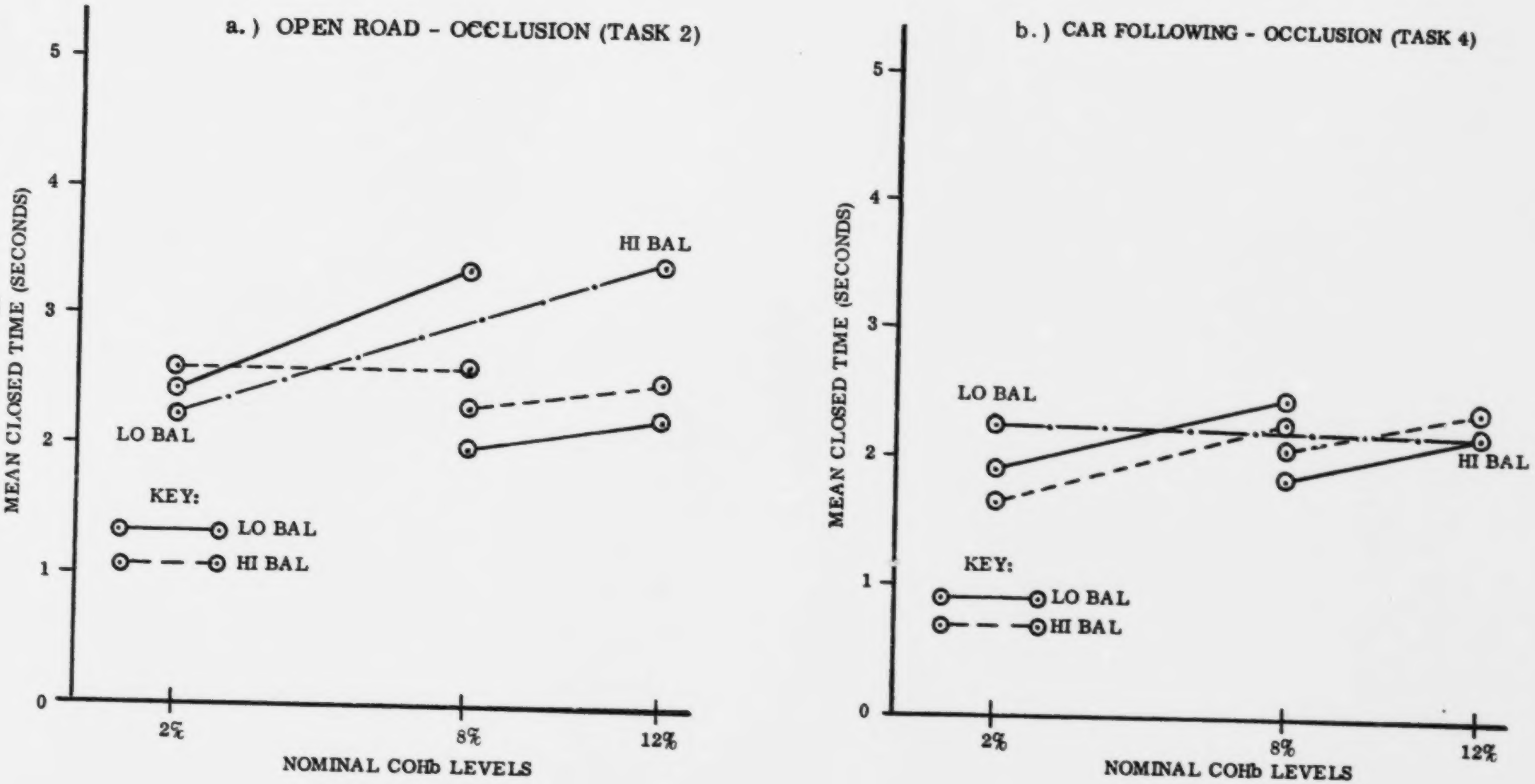

Figure 3.8. -- Mean Closed Time (Seconds) vs. Nominal COHb Levels

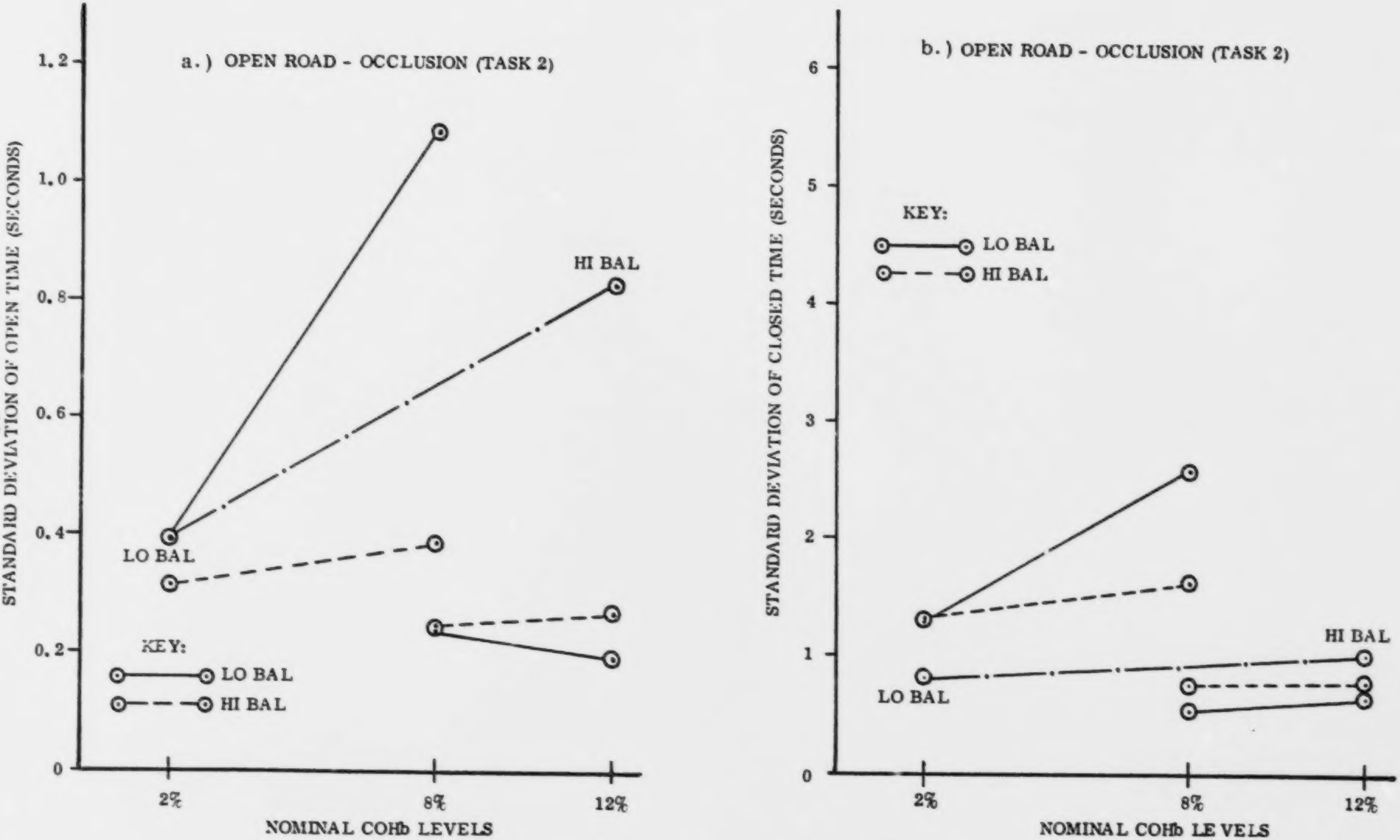

Figure 3.9. -- Standard Deviation of Open and Closed Times During Open Road Occlusion Task vs. Nominal COHb Levels

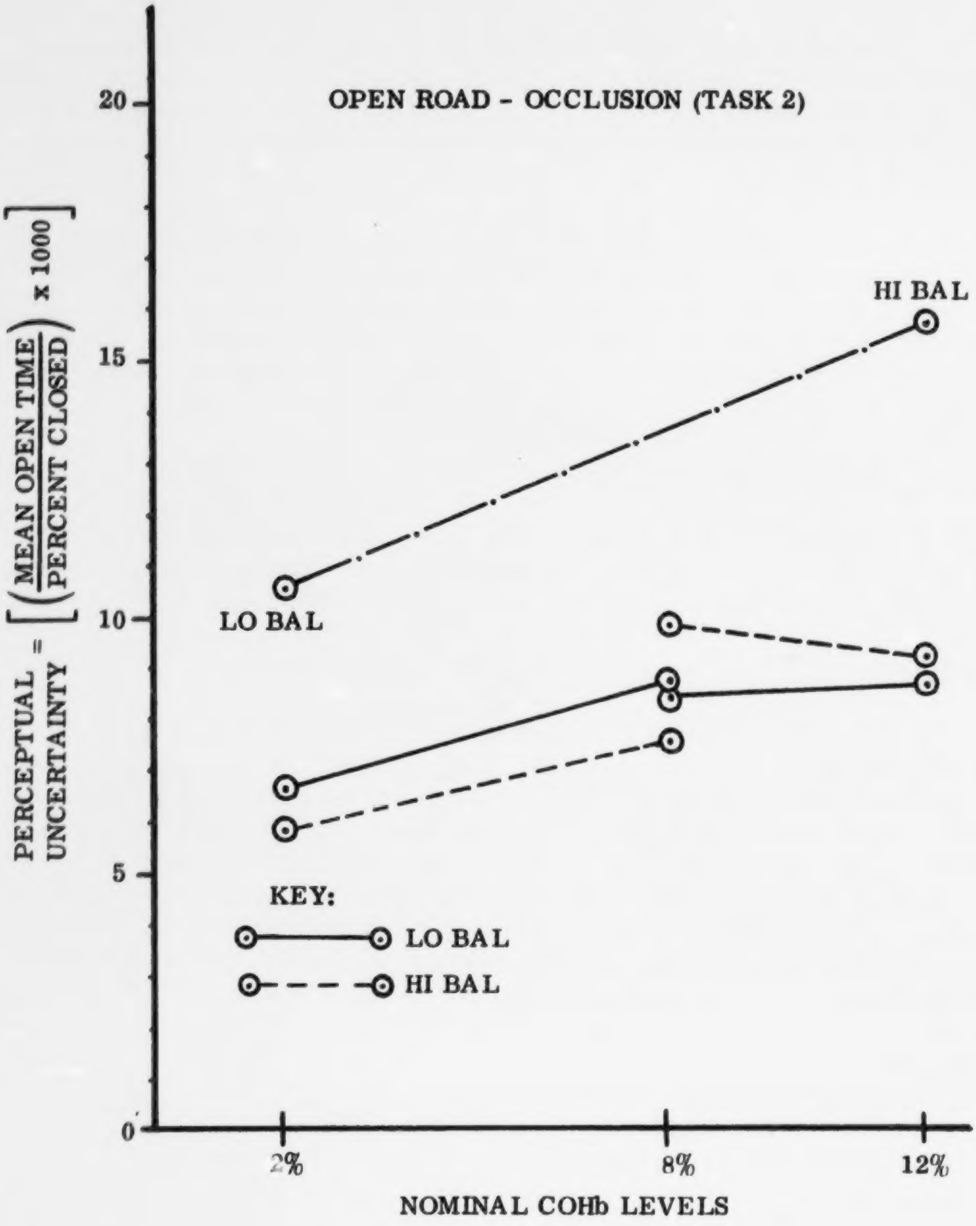

Figure 3.10. -- Perceptual Uncertainty vs. Nominal COHb Levels (Open Road Driving with Voluntary Occlusion)

The object code from T6 (car following task) which was analogous to the FE code in T5, was that defined as LC (lead car), representing looks at the lead car. This visual behavior was again defined in terms of the mean, standard deviation, and percentage of time spent looking at the LC code, or lead car in this case.

Another measure which was investigated in both open road driving and car following was mean inter-sample time away from FE code or LC code. This measure gives the average time of the intervals during which the subject was willing to be without information from the straight road scene (FE or LC code). The results of object code analysis are summarized in Tables 3.4a and b.

3.4.1 Open Road Driving (Task 5)

In general, the object code analysis for the eye-movement data from open road driving did not show any statistically significant results. But the following trends were observed in various categories of effects.

COHb Effect:

The mean time in FE Code increased almost 50% with 8 and 12% COHb level showing an additive effect (see Figure 3.11a). The percent of total time in FE decreased by about 5% from 0-8% COHb level and it was not affected by CO in the range of 8-12% COHb level (see Figure 3.12a). Mean time away from the FE Code showed slight increase with increasing COHb level. The results from these three measures suggest that the total time spent by the driver in the scene ahead does not change whereas the driver makes fewer eye movements and fixates for longer durations; i.e., the driver's eye movement activity is reduced or information seeking time is increased due to the COHb effect.

BAL Effect:

The Standard Deviation of time in FE increased slightly with HI BAL. A similar effect was also observed for mean time away from FE.

Interaction:

Mean time in FE was decreased with 8% COHb-HI BAL. This decreasing trend was also observed for mean time in FE with 12% COHb-HI BAL, when compared with 2% COHb-LO BAL conditions (see Figure 3.11a). Therefore, there is a general tendency for alcohol, when combined with CO, to act antagonistically and reduce the effect of CO.

Table 3. 4a

Summary of Results -- Visual Behavior Measures (Object Code)

1. Trend and Significance

		Phase 1			Phase 2			Phase 3
Task	Measure	8% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb Effect	.05% BAL Effect	CO x BAL Interaction	12% COHb with .05% BAL
Open Road Driving (T5)	Mean Time in FE	+	N	- with 8% COHb, HI BAL	+	N	- with 8% COHb, HI BAL	-
	S. D. of Time in FE	N	+	- with 8% COHb, HI BAL	N	+	N	-
	Percent in FE	-	N	N	N	-	N	-*
	Mean Time Away From FE	+	+	N	+	N	+ with 8% COHb, HI BAL	-
Car Following (T6)	Mean Time at LC	+*	+	N	N	N	- with 12% COHb, HI BAL	-*
	S. D. Time at LC	+	N	- with 8% COHb, HI BAL	+	N	- with 12% COHb, HI BAL	-
	Percent Time at LC	+*	N	- with 8% COHb, HI BAL	N	N	- with 12% COHb, HI BAL	-
	Mean Time Away From LC	+	+	N	N	N	- with 12% COHb, HI BAL	-

+ increasing trend
- decreasing trend
* significant (p < .1)
N no trend

Table 3.4b

Summary of Results -- Visual Behavior Measures (Object Code)

2. Interaction and Bench Mark

Task	Measures	Nature of Interaction		Bench Mark	
		Phase 1	Phase 2	Phase 1	Phase 2
Open Road Driving(T5)	Mean Time in FE	A	N	BAL < CO	BAL < CO
	S. D. of Time in FE	A	N	BAL > CO	BAL ≈ CO
	Percent in FE	N	N	BAL > CO	BAL < CO
	Mean Intersample Time	N	A	BAL ≈ CO	BAL > CO
Car Following (T6)	Mean Time at LC	N	A	BAL ≈ CO	BAL > CO
	S. D. of Time at LC	A	A	BAL < CO	BAL < CO
	Percent of Time at LC	A	A	BAL ≈ CO	BAL ≈ CO
	Mean Intersample Time	N	A	BAL ≈ CO	BAL > CO

N No trend
S Synergism
A Antagonism
≈ approximately equal

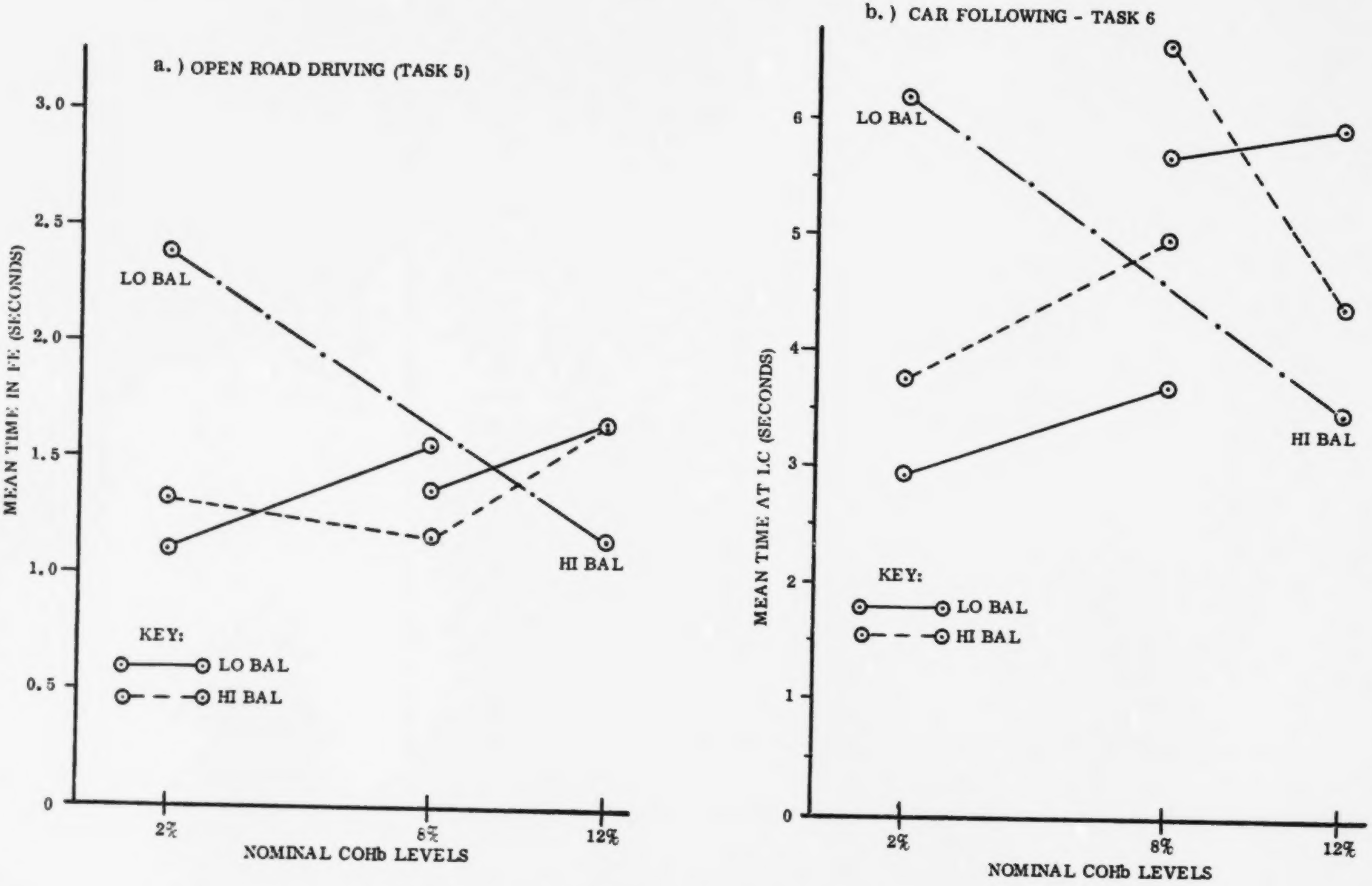

Figure 3.11. -- Mean Time in FE and LC Code (Object Code Analyses) vs. Nominal COHb

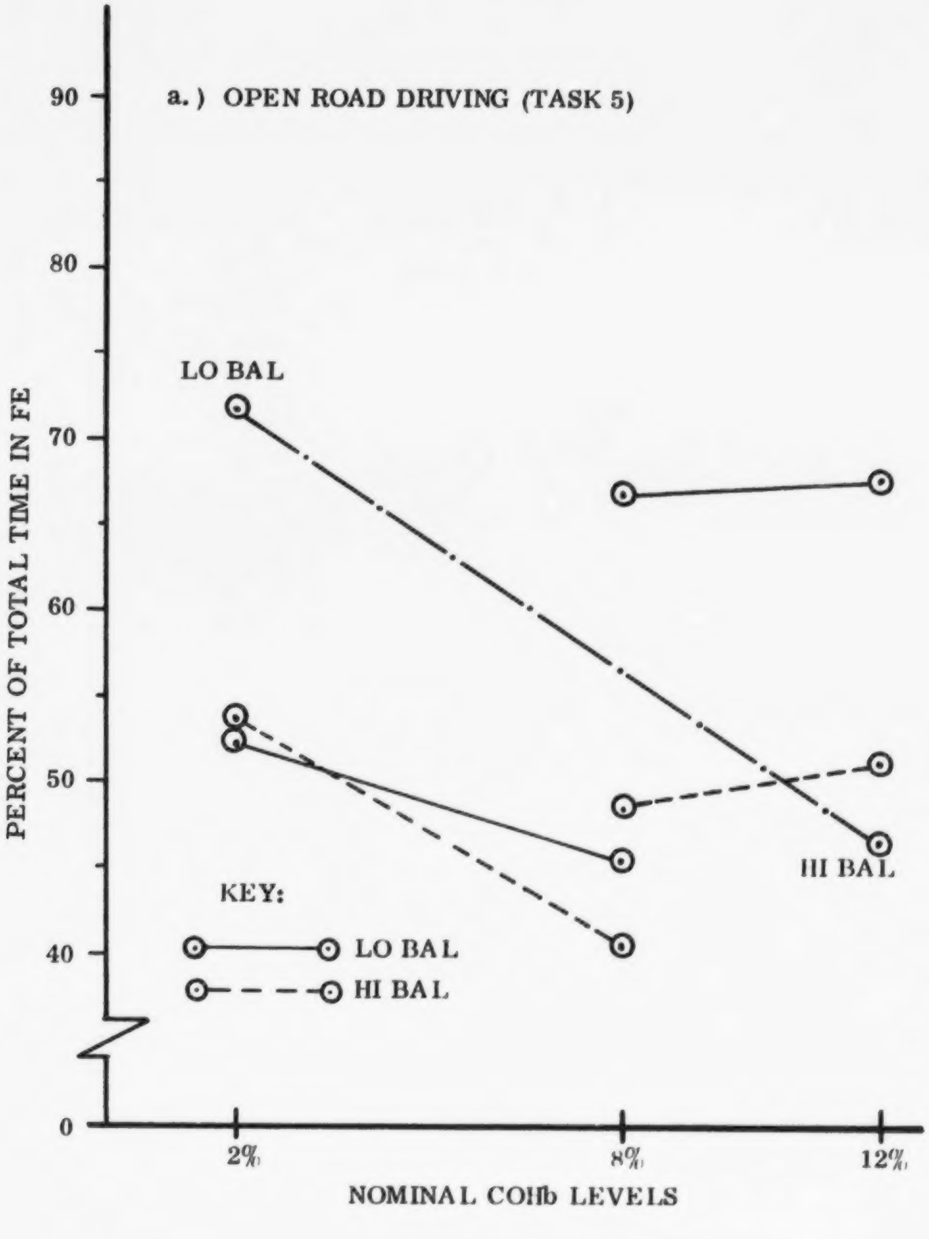

Figure 3.12a. -- Percent of Total Time in FE Code vs. Nominal COHb Level

Standard Deviation of time in FE was also reduced with CO-alcohol interaction. Mean time away from the FE code and percent time in FE decreased with 12% COHb-HI BAL compared with 2% COHb-LO BAL conditions.

3.4.2 Car Following (Task 6)

COHb Effect:

In the car following task the mean and Standard Deviation of time at the lead car and percent of total time at the lead car all showed an early COHb effect and increased at 8% COHb (see Figures 3.11b, and 3.12b). The changes in the mean time and in the percent time at the lead car were significant in 0-8% COHb level range ($p = 0.06$, $p = 0.08$). Here again the results suggest that there is evidence of reduced eye-movement activity under the effect of CO based on the explanation given in Section 3.4.1.

BAL Effect:

There was no appreciable influence of alcohol on the Standard Deviation of time and percent time at the lead car. However, a slight increase in mean time at the lead car and mean time away from the lead car was observed in the 2-8% COHb level range.

Interaction:

The effects due to CO-alcohol interaction when both were at higher levels were observed to be consistently antagonistic for all the four measures. The general effect was one of decrement in mean and S.D. of time at LC, percent of total time at LC and mean time away from LC. The mean time at LC decreased significantly ($p < 0.1$) with 12% COHb, HI BAL in Phase 3.

From 3.11a and 3.11b it can be seen that the mean look durations at the lead car are greater than the mean look durations in the FE region. Similarly from Figures 3.12a and 3.12b it can be seen that the percent time at LC is greater than the percent time in FE region. These differences indicate the task difference between open road driving and car following, indicating that a lead car is a primary source of information which is to be obtained by the driver.

3.5 Visual Sign Reading Behavior in Freeway Driving

The sign reading measures were obtained from reduction of the eye-movement data collected during the freeway driving of T7. The measures used in this study were originally developed in previous signing research by Bhise

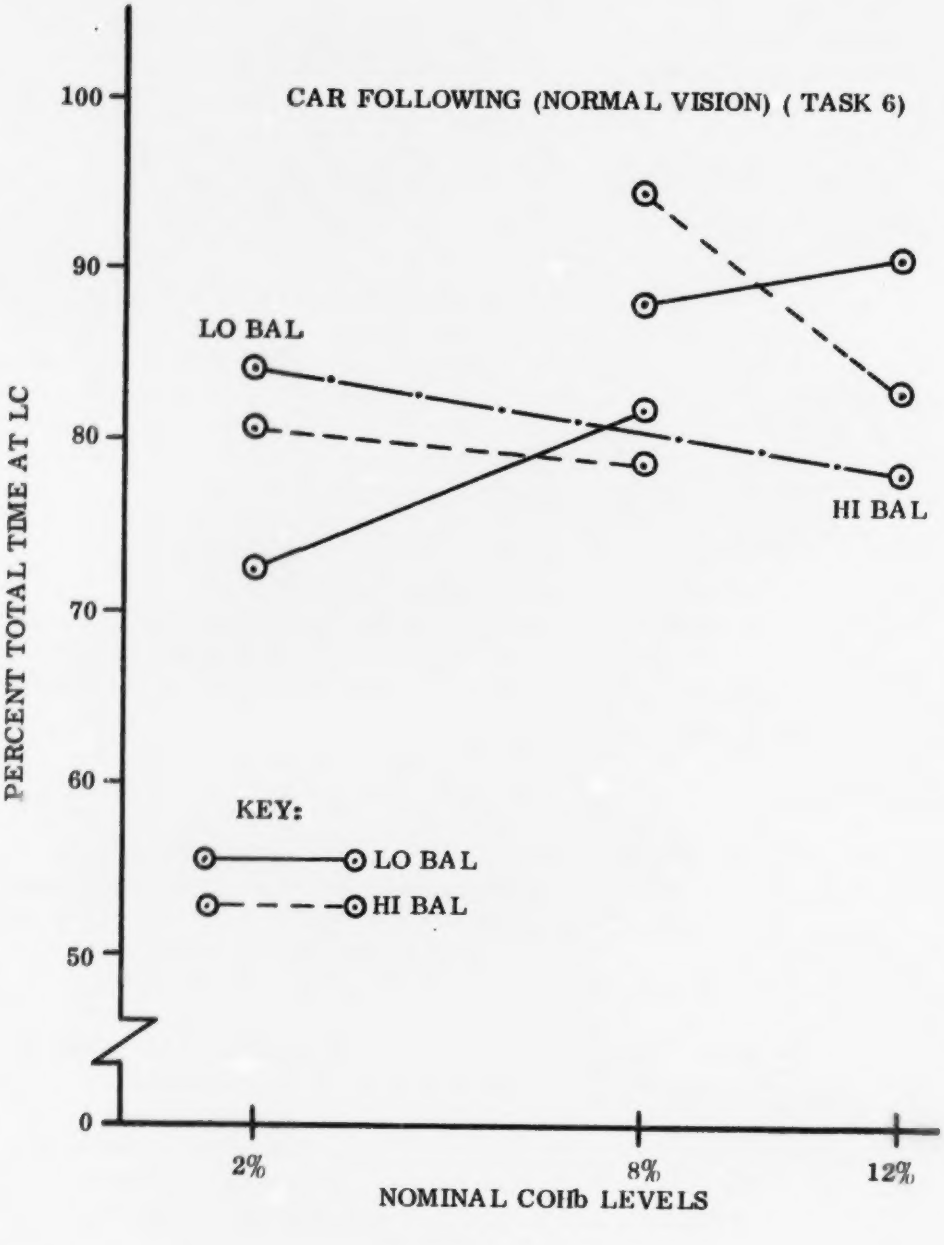

Figure 3.12b. -- Percent of Total Time in LC Code vs. Nominal COHb Level

and Rockwell (1972). Variables of primary interest included the time between the first sign look and subsequent passage past the sign (T_f), and the total amount of time spent looking at the sign (T_{used}). There were three signs of interest during this task and the average T_{used} and T_f were considered for analysis.

The two measures are described in Figure 3.13. To obtain the above measures, the video tape was analyzed for about 2000 feet of travel for each of the three signs (the distance, 2000 feet, was accounted backwards from the sign).

Results from the sign reading behavior measures is given in Table 3.5. Figures 3.14a and 3.14b graph the two measures (T_{used} and T_f) vs. nominal COHb levels.

COHb Effect:

COHb effect on T_{used} was similar to the adaptation effect explained in Section 3.1.1. In the range 0-8% COHb level the average T_{used} was decreased and in the range 8-12% COHb level, the average T_{used} increased (see Figure 3.14a). This is again a phenomena which needs further research. Even though the results are not statistically significant, the observed difference of five to six seconds in average T_{used} may be practically significant since five to six seconds at 50 mph amounts to about 500 feet of travel.

Average T_f showed an early decrease with 8% COHb level and was not affected in the 8-12% COHb level range (see Figure 3.14b). The decrement in T_f may be attributed to reduction of eye-movement activity due to COHb effect.

Theoretically speaking, reduction in T_f indicates poor performance (late sign sampling) and COHb has a tendency in this direction.

BAL Effect:

In the 8-12% COHb level range the BAL effect was significant ($p < 0.8$) reducing the average T_{used}. The BAL effect also reduced the average T_f (see Figures 3.14a and 3.14b).

Interaction:

CO-alcohol interaction was significant ($p < 0.01$) for average T_{used} when HI BAL was combined with 8% COHb level. The interaction was antagonistic in nature.

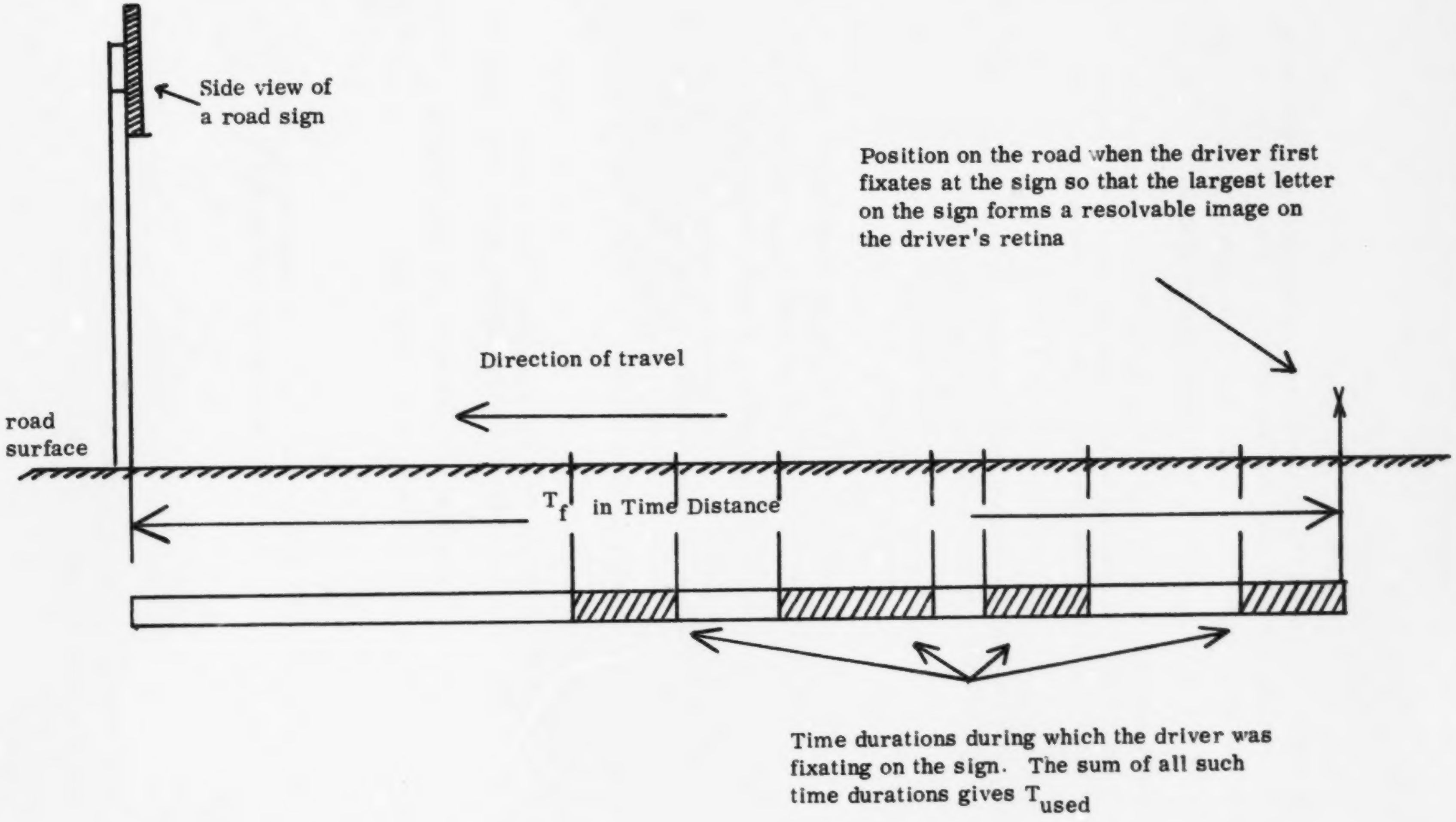
Side view of a road sign
Position on the road when the driver first fixates at the sign so that the largest letter on the sign forms a resolvable image on the driver's retina
Direction of travel
road surface
T_f in Time Distance
Time durations during which the driver was fixating on the sign. The sum of all such time durations gives T_{used}

Figure 3.13--Schematic diagram explaining T_f and T_{used} in sign reading

Table 3.5

Summary of Results - Sign Reading Behavior

1. Trends and Significance

	Phase 1			Phase 2			Phase 3
Measure	8% COHb Effect	.05% BAL Effect	COxBAL Interaction	12% COHb Effect	.05% BAL Effect	COxBAL Interaction	12% COHb with .05% BAL
T_{used}	-	N	+* with 8% COHb, HI BAL	+	-*	N	-
T_f	-	N	N	N	-	N	N

2. Interaction and Bench Mark

	Nature of Interaction		CO-Alcohol Bench Mark	
Measure	Phase 1	Phase 2	Phase 1	Phase 2
T_{used}	A	N	BAL ≈ CO	BAL < CO
T_f	N	N	BAL > CO	BAL < CO

+ increasing trend
- decreasing trend
* statistically significant ($p < .10$)
N no trend
S synergism
A antagonism
≈ approximately equal

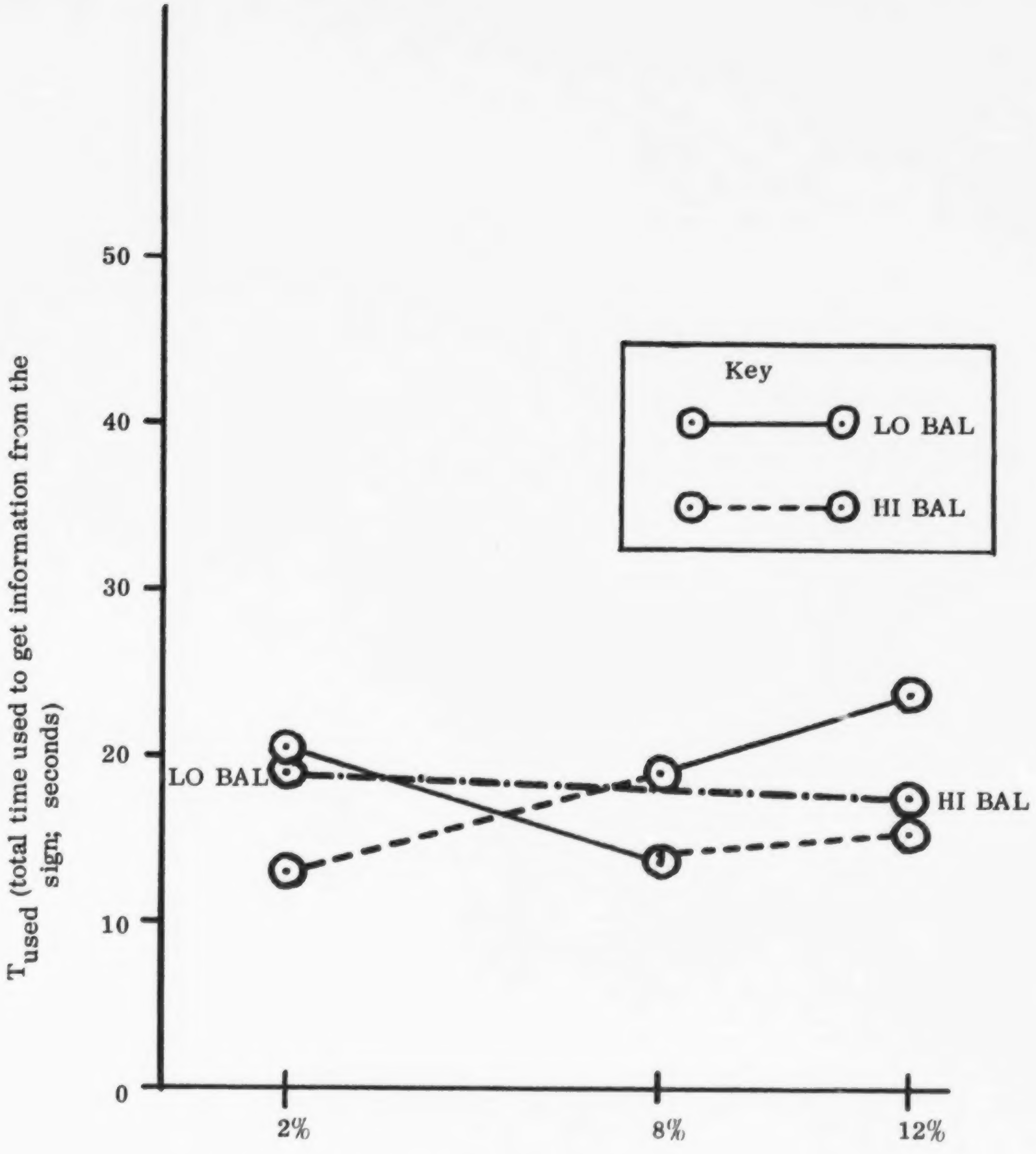

Figure 3.14a. --T_{used} versus Nominal COHb Levels
(Sign Reading Task)

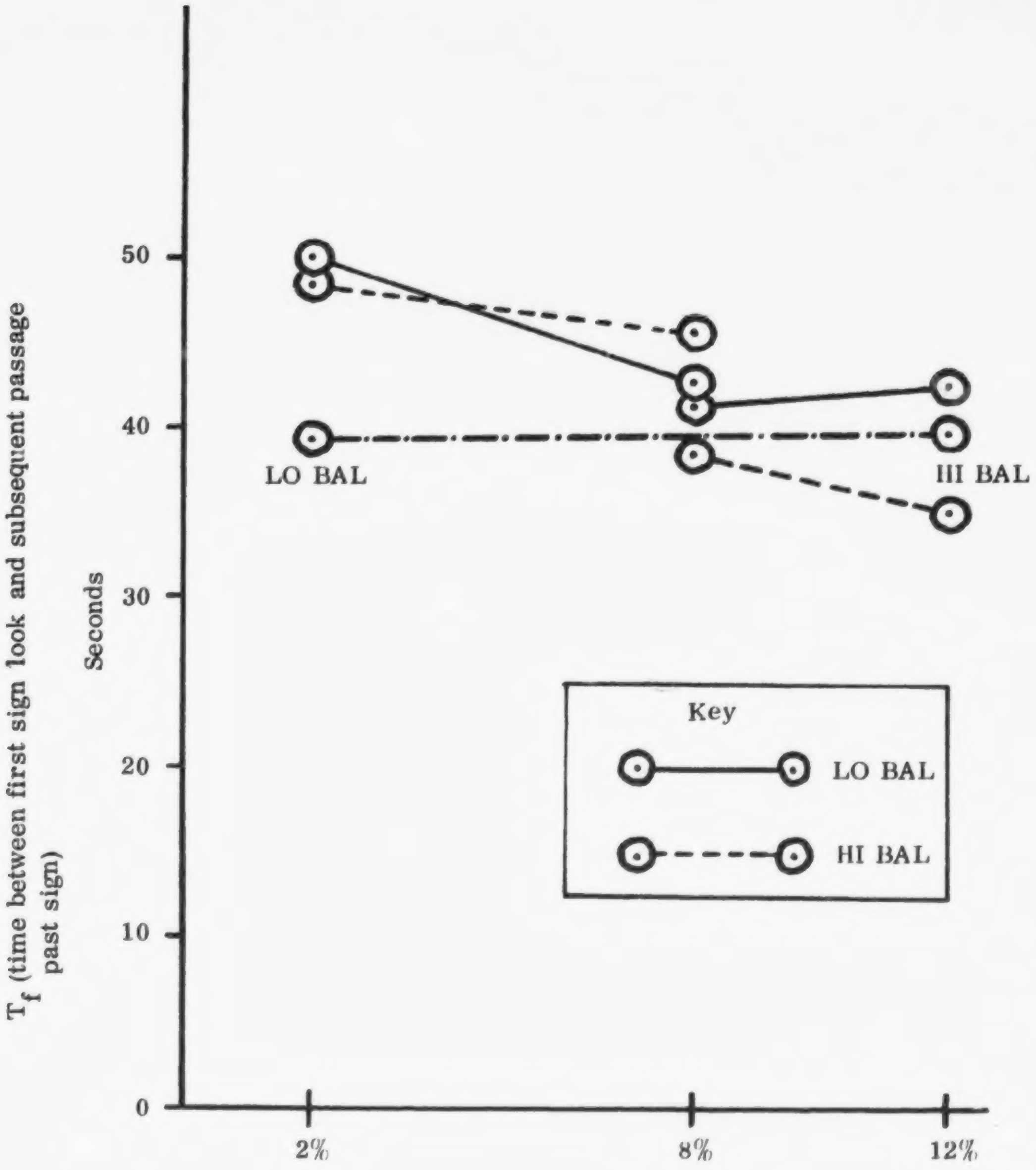

Figure 3.14b.--T_f versus Nominal COHb Levels (Sign Reading Task)

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Introduction

This research investigated driver performance under the combined effects of carbon monoxide and alcohol. In the past, only very few studies, Rockwell and Ray (1967), Rockwell and Weir (1973), Safford (1971), McFarland (1973) have investigated the effects of CO on highway driving. Although alcohol effects on performance have been studied to a greater extent, not much research has been carried out on visual behavior of drivers under the influence of alcohol (Perrine, 1973).

While earlier research answered questions about driver performance under the individual effects of CO and alcohol, this research attempts to provide some insights into their combined effects.

The remainder of this chapter will be organized in the following manner:

1. effect of COHb,
2. interactive effects,
3. bench mark relations,
4. subject variability and learning, and
5. recommendations for further research.

4.2 Effect of COHb

In the literature review section of Chapter 1, based on the past literature on COHb effects on driving performance, the following four hypotheses were derived, i.e., elevated COHb levels cause

1. perceptual narrowing,
2. decreased visual activity,
3. time compression, and
4. distance expansion.

It will now be shown that the results of this research can be explained by the above four hypotheses in the case of COHb effects.

The results of COHb effects from this study are summarized in Table 4.1 by the nature of COHb effects, i.e., early threshold, late threshold, additive,

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Table 4.1

Summary of Major COHb Effects

Measure	Task	Nature of COHb Effects: Early Threshold 0-8-12%	Late Threshold 0-8-12%	Additive 0-8-12%	Adaptation 0-8-12%
Steering Wheel Reversals/mt	Curve	* ╱‾	-	-	-
Steering Wheel Reversals/mt	Open Road (O.R.)	-	-	-	∧
Headway Mean	Occlusion - C. F.	-	‾╲ ***	-	-
Headway S. D.	Occlusion-C. F.	╱‾	-	-	-
Mean Open Time	Occlusion-O. R.	╱‾	-	-	-
S. D. Open Time	"	-	-	-	∧
Mean Closed Time	"	-	-	*** ╱	-
S. D. Closed Time	"	* ╱‾	-	-	-
Mean Open Time	Occlusion-C. F.	-	_╱	-	-
S. D. Open Time	"	╲_	-	-	-
Mean Closed	"	-	-	* ╱	-
S. D. Closed	"	-	_╱	-	-
Percent of Total Time Closed	"	╱‾	-	-	-
Mean Time in FE	Open Road	-	-	╱	-
Percent Time in FE	"	╲_			
Mean Time in LC	Car Following	* ╱‾	-	-	-
SD Time in LC	"	-	-	╱	-
Percent Time in LC	"	* ╱‾	-	-	-
T_f	Sign Reading	╲_	-	-	-
T_{used}	"	-	-	-	∨

Note:

O. R. Open Road Driving
C. F. Car Following
Statistical Significance * $p \leq 0.1$
*** $p \leq 0.01$

and adaptation effects. The reader is referred back to Section 3.1.1 for explanation of different COHb effects. The first conclusion from this table is, there are not many adaptation effects. Even the three measures which showed this effect indicate only trends and not statistical significance of the effect. This indicates that for 0-8-12 COHb level range, the COHb effects are mostly either additive or threshold type. These effects are interpreted on the basis of previous research findings in the following discussion. Figure 4.1 offers an explanation for the observed results based upon past derived hypotheses.

In the driver control measures it was observed that steering wheel reversal rates while negotiating through curves is significantly higher at 8% COHb level showing the early threshold type of COHb effect. This could be explained on the basis that driver's information processing rate decreases at elevated COHb levels. Curve negotiation is a high level dual control tracking task, and any reduced rate of information processing would affect the driver's control movements resulting in a higher number of steering corrections. However, this effect was not observed in open road driving.

Another interesting result in the steering performance is that the magnitudes of average SWR/minute at 2 and 12% COHb levels in open road driving from the previous study, and this study are approximately the same: at 2% COHb levels 36 and 38 and at 8% COHb levels 32 and 27 respectively.

In the vehicle state measure, mean headway during car following with voluntary occlusion showed a significant decrease in the 8-12% COHb range. This result is explained in Figure 4.1 based on the evidence provided by Ray (1967) that drivers tend to overestimate distances at higher COHb levels.

The results of spare visual capacity measures show that at elevated COHb levels there is an increasing trend in perceptual uncertainty (see Figures 3.7 and 3.10). Even though these results were not statistically significant, they show the same trend that was observed in the previous study. One interesting result which was observed in this study and not in the previous study, is the mean closed time during which the subjects volunteered to close their eyes and drive without seeking information. This measure significantly increased in the 2-8% COHb range during open road driving and in the 8-12% range during car following. This result is surprising in the sense that one would expect the driver to close his eyes for some constant time depending on his spare visual capacity and risk-taking behavior. But what is observed is an increased 'closed' time at elevated COHb levels which may be explained on the basis of hypothesized time compression at higher COHb levels.

The results from object code analysis show both in open road driving and car following the average look duration straight ahead on the road scene increased

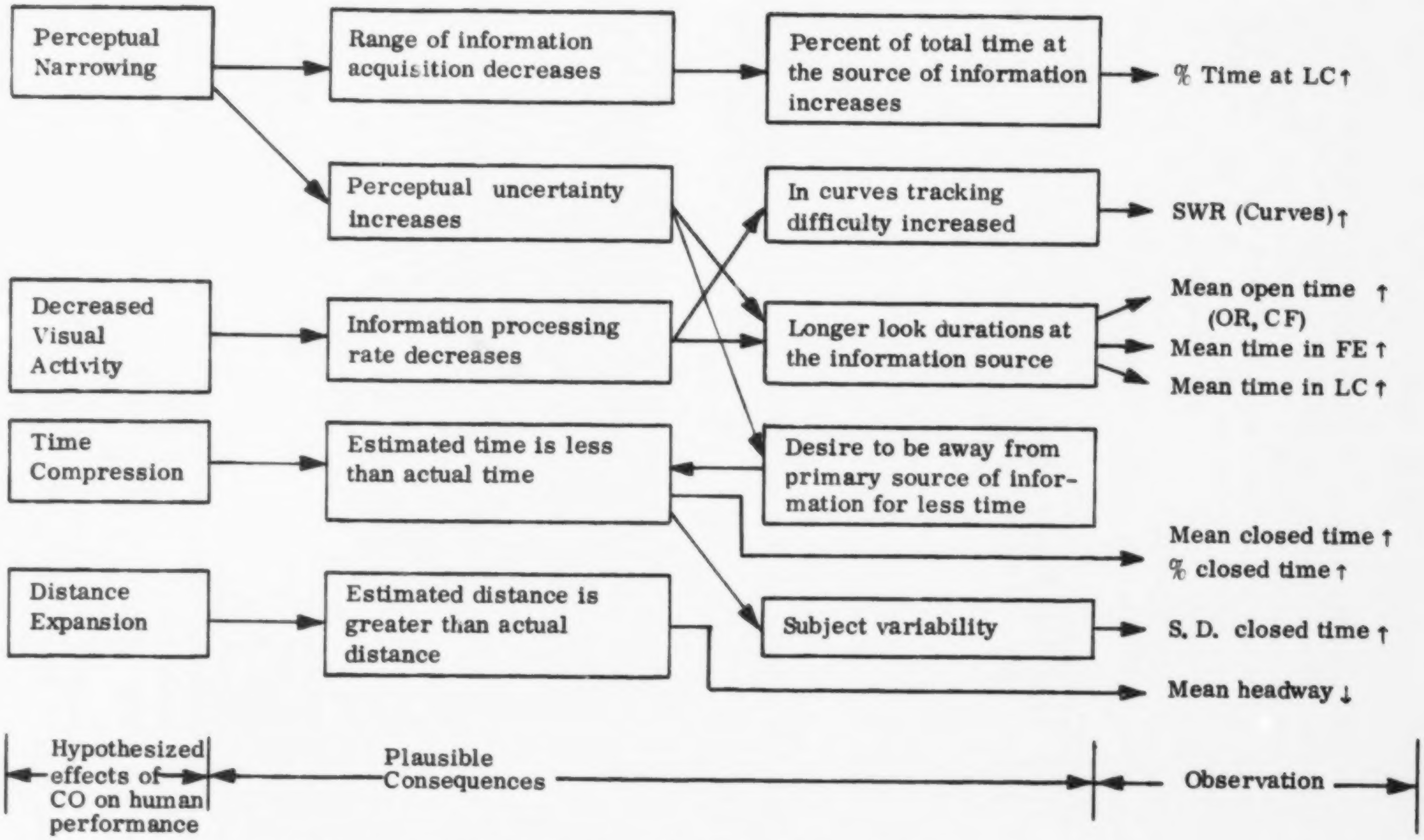

Perceptual Narrowing
Range of information acquisition decreases
Percent of total time at the source of information increases
% Time at LC↑
Perceptual uncertainty increases
In curves tracking difficulty increased
SWR (Curves)↑
Decreased Visual Activity
Information processing rate decreases
Longer look durations at the information source
Mean open time ↑ (OR, CF)
Mean time in FE ↑
Mean time in LC ↑
Time Compression
Estimated time is less than actual time
Desire to be away from primary source of information for less time
Mean closed time ↑
% closed time ↑
Distance Expansion
Estimated distance is greater than actual distance
Subject variability
S. D. closed time ↑
Mean headway ↓
Hypothesized effects of CO on human performance
Plausible Consequences
Observation

Figure 4. 1. --Effect of COHb--An Interpretation of Results with elevated COHb levels, causing the information acquisition rate to be decreased. Also the fact that the driver spent higher percent of total time on the lead car with longer look durations supports the concept of decreased visual activity at elevated COHb levels.

In conclusion, the COHb effects very clearly indicate the following:

1. Significant results were observed only in the threshold and additive type of effects. No significant result was observed with the adaptation property as proposed in the earlier report.

2. A second interesting point is that significant results were shown only from more difficult tasks such as curve negotiation, car following with occlusion, and car following with normal vision (without occlusion). This result is an important message for researchers in this area, indicating that the subjects' compensating ability should be removed such that the effect of COHb, if present, can be observed from the results.

3. The results of this research are in substantial agreement with the earlier work on this context.

4.3 Interactive Effects of CO and Alcohol

In order to interpret the CO-alcohol interaction it is necessary to make a few comments on the BAL effects on driving performance. From the Belt (1969) study it is clear that increased BALs cause impairment in peripheral activity, and lateral control and increased look durations. According to Perrine (1973) there is evidence to consider that low BALs (less than .08%) act in an excitatory manner or do not affect visual performance. Moskowitz (1973) in a review of a number of alcohol studies related to driving states that tracking combined with high information processing demands gets affected even at low BALs (0.05%). These results support some of the observations made on the CO-alcohol interaction effects in this study. Table 4.2 gives a summary of interactive effects from this study.

It should be kept in mind that the target BAL in this study was 0.05% and average of actual levels during the experiments was 0.041%. Based on the earlier discussion of the previous literature, it is reasonable to expect performance degradation in curve negotiation which is a tracking task associated with higher information processing demands. Referring to Figure 3.5b it can be seen that alcohol acts synergistically with CO at 12% COHb increasing the SWR/minute in curves. Also the interaction at 12% COHb level is significantly synergistic in increasing the peak lateral acceleration in the curves. This increase is again a sign of decreased driver performance due to interaction effect under task stress.

Table 4.2

Summary of Interactive Effects

Measure	Task	Phase 1 0 - 8%	Phase 2 8 - 12%
SWR/Rate	Curve	-	*S
Peak lateral 'g'	"	A	*S
Mean Open Time	OR-OCC	A	S
S.D. Open Time	"	A	*S
Mean Closed Time	"	A**	-
S.D. Closed Time	"	A	-
Mean Open Time	CF-OCC	S	A
S.D. Open Time	"	S	A
Percent Time Closed	"	A	S**
S.D. Closed	"	-	A
Mean Time in FE	OR	A	-
S.D. of Time in FE	"	A	-
Mean Time in LC	CF	-	A
S.D. of Time in LC	"	A	A
Percent Time in LC	"	A	A
T_{used}	Sign Reading	A***	-

Key

OR - Open Road Driving, CF - Car Following,
Occ - Occlusion

S - Synergism

A - Antagonism

Statistical Significance * $p < 0.1$
** $p < 0.05$
*** $p < 0.01$

In the occlusion tasks the CO-alcohol interaction produced a combination of both antagonistic and synergistic effects barring any possible explanation of driver behavior. One of the reasons might be due to task novelty. From the object code analysis it can be seen that none of the interactions were significant but an interesting result is that the nature of interaction is mostly antagonistic. It was explained earlier how COHb effect caused performance decrement in visual behavior of drivers. Now there is evidence to believe that low BALs such as 0.04 to 0.05% act excitatorily producing antagonistic results when combined with CO. If the 'bi-phasic' effects of alcohol on visual behavior as suggested by Perrine (1973) are true, the results of CO-alcohol interaction from this study is not surprising. Also the researchers feel that BALs as high as 0.08% to 0.1% may produce synergistic type of interaction when combined with CO. Thus, under the test conditions it is safe to conclude that 0.04% BAL will either have no interaction effect with CO or may even offset CO effects.

4.4 Bench Mark Relations

The objective of studying bench mark relations is to determine whether or not the pure BAL effect is greater than pure COHb effect. In Phase 1, since the COHb levels were 2 and 8%, this comparison is possible. In Phase 2, since the COHb levels used were 8 and 12%, the COHb effect will be relative to 8% COHb effect. Hence the question of bench mark relations can only be answered from Phase 1 results. (See Figure 3.4 for graphical depiction.) By looking at the Phase 1 results in Table 4.3 for occlusion tasks it can be seen that both open times and closed times are less affected by alcohol than CO. Mean time in FE is also less affected by alcohol although the percent time in FE is more affected by alcohol than CO. These results indicate that the driver's visual activity suffers less due to alcohol than CO. This result also explains the observed T_f values in sign reading. Larger value of T_f means the driver makes his first fixation at the sign far in advance of passage. The bench mark relation for T_f suggests that it is greater due to alcohol than CO, which again may be due to less visual activity decrement due to alcohol than CO. For vehicle state measures and driver control measures, the results are ambivalent. The general conclusion is that 0.04% BAL has even less effect on driver performance than 8% COHb level.

4.5 Subject Variability and Learning

Referring to ANOVA tables in Appendix H, it can be seen that in more than 50% of the analyses, subject effect was significant. This indicates that even within a class of subjects (young) there is quite an inconsistency in the behavior due to the effect of CO. This seems to be the serious problem in research which investigates subtle effects like COHb effects.

Table 4.3

Summary of Results on Bench Mark Relations

Task	Measure	Phase 1 0-8% BAL-CO	Significant COHb effects in the 0-8% range
OR	SWR	<	
Curve Driving	SWR	<	*
	Peak Lateral 'g'	>	
	Vel Reduction	-	
CF-Normal	Mean Headway	-	
CF-Normal	S.D. Headway	>	
CF-Occlusion	Mean Headway	>	
CF-Occlusion	S.D. Headway	<	
OR-Occlusion	Mean Open Time	<	
OR-Occlusion	S.D. Open Time	* <	
OR-Occlusion	Mean Closed Time	*** <	***
OR-Occlusion	S.D. Closed Time	* <	*
CF-Occlusion	S.D. Open Time	>	
CF-Occlusion	Mean Closed Time	** <	
CF-Occlusion	S.D. Closed Time	<	
CF-Occlusion	Percent Time Closed	<	
OR	Mean Time in FE	<	
OR	S.D. of Time in FE	>	
OR	Percent Time in FE	>	
CF	Mean Time in LC	<	*
CF	S.D. of Time in LC	<	
CF	Percent Time in LC	<	*
Sign Reading	T_{used}	-	
Sign Reading	T_f	>	

Key: OR-Open Road Driving, CF-Car Following

0.05% BAL effect is less than 8% COHb effect
0.05% BAL effect is greater than 8% COHb effect
*** Statistically Significant $p < 0.01$
** Statistically significant $p < 0.05$
* Statistically significant $p < 0.1$

With reference to learning, it is interesting to note that the day effect (learning effect) was significant mostly in tasks with voluntary occlusion. This task is quite novel and is not a usual driving task. The fact that day effect was absent in tasks other than occlusion supports the general notion that driving is a highly learned task. One way to reduce learning in novel tasks is to give the subjects enough training before data collection or as was done in this study to counterbalance the design such that the major effects are not contaminated.

4.6 Recommendations for Further Research

This research reveals certain interesting results and suggests the following for further research:

1. Observation of subtle COHb effects seems to be directly related to task difficulty. So any attempt to research the COHb effect on driving performance should be directed toward the driving situations where human compensation is eliminated as much as possible.

2. Another suggestion to research COHb effect is to use subjects from susceptible population; i.e., drivers who will be more susceptible to the effect of COHb than young, healthy college students. This suggestion looks at a kind of worst situation with the expectation that the susceptible subjects might be in any of the following conditions or situations:
    - a. the subject's compensating ability under task stress is minimum, e.g., aged drivers;
    - b. the subject's oxyhemoglobin level is less because of oxygen deprivation; e.g., driving in tunnels or at high altitudes; and
    - c. subjects may have a low or limited tissue oxygen; e.g., people who have anemia, pulmonary insufficiency, or cardiovascular disease.

3. To increase task difficulty, one suggestion is to test the subjects under the influence of CO during night, since night driving imposes limitations on visual information input to the driver.

4. There is evidence from this study to conclude that 0.05% BAL acts synergistically with CO and decreases driver control performance. Also 0.05% BAL acts in an excitatory manner producing antagonistic results in visual behavior measures. In practice BALs much greater than 0.05% are quite common. Hence to get evidence on the CO-alcohol interaction, reflecting

to a more common and realistic driving situation, it would be fruitful to extend the present study with BALs at least 0.08% or greater. This would also add additional insights to CO-alcohol bench mark relations.

APPENDIX A

STATISTICAL MODELS USED IN THE ANALYSES

Phases 1 and 2

The Latin Square Design assumes that the interactions between the factors (subject, day and treatment) do not exist. Hence the model is written as:

$$Y_{ijk} = M + S_i + D_j + T_k + e_{ijk}$$

where Y_{ijk} is the observed value of the dependent variable corresponding to subject i, day j and treatment k; $i = 1, 2, 3, 4$; $j = 1, 2, 3, 4$; $k = 1, 2, 3, 4$.

M is a constant

S_i is the effect due to subject i

D_j is the effect due to day j

T_k is the effect due to treatment k and

e_{ijk} is the error term, $NID(0, \sigma_e^2)$

Since the main objective of this research is to study the effect of CO-alcohol interaction, the treatment sum of square is partitioned as BAL effect, CO effect, and BAL x CO interaction.

In order to take into account any missing data a regression model has been used as an alternative model for analyses The model is as follows:

$$Y_{ijk} = A_0 + \sum_{m=1}^{9} A_m X_m + e_{ijk}$$

where A_i, $i = 0, 1, \ldots, 9$ are regression coefficients

X_1, X_2, X_3 are the three orthogonal subject contrasts

X_4, X_5, X_6 are the three orthogonal day contrasts

X_7 is the contrast due to the BAL effect

X_8 is the contrast due to the CO effect and

X_9 is the contrast due to the BAL x CO interaction.

In cases where learning was very insignificant the model was revised to give more degrees of freedom for the error. The model is as follows:

$$Y_{ijk} = A_0 + \sum_{m=1}^{3} A_m X_m + \sum_{m=7}^{9} A_m X_m + e_{ijk}$$

Phase 3

A direct regression model was used to analyze data of Phase 3.

$$Y_{ijk} = A_0 + \sum_{m=1}^{5} A_m X_m + e_{ijk}$$

where Y_{ijk} is the observed value corresponding to subject i, day j, treatment k; $i = 1, 2, 3, 4$; $D = 1, 2$; $T = 1, 2$

A_i, $i = 0, 1, 2, \ldots, 5$ are regression coefficients

X_1, X_2, X_3 are three orthogonal subject contrasts

X_4 is day contrast

X_5 is treatment contrast and

e_{ijk} is error term $NID(0, \sigma_e^2)$.

An alternate model where learning does not take place is given by

$$Y_{ijk} = A_0 + \sum_{m=1}^{3} A_m X_m + A_5 X_5 + e_{ijk} \cdot$$

APPENDIX B

SUBJECT INSTRUCTIONS FOR ROAD TESTS

TASK 1 Velocity/Time Estimation

Subject Instructions:

During this part of the experiment, you will be driving the vehicle without the use of the speedometer. I will instruct you to a certain speed by telling you to "slow down" or "speed up" informing you when you have achieved the proper speed. I want you to hold that speed as accurately as you can. While holding that speed, I will present an interval of time signified by the words, "start" and "stop". I then want you to give me two numbers - first your estimate of that speed and, second, your estimate of the time interval. Are there any questions?

TASK 2 Open Road - Voluntary Occlusion

Subject Instructions:

During this part of the experiment, we want you to drive this car in your normal manner at about 50 or 60 mph. Please stay in the right lane.

In addition, we would like you to drive with your eyes closed as much as possible, but make sure you keep the car within the white lane markers. I repeat: You must keep the car within the white lane markers. The safety man seated next to you will tell you to "open" if it becomes necessary - but you should not rely on him at all. If you are performing the task correctly and keeping the car within the white lane markers, he won't have to say "open" except for occurrences other than going out of your lane. Are there any questions?

TASK 3 Curvature Task

Subject Instructions:

During this part of the experiment, we would like you to drive in your normal manner to a place where we will tell you to turn around. At that time, I will ask you to estimate how much time it

TASK 1

	SPEED		TIME	
	CONTROL	ESTIMATE (MPH)	CONTROL (SEC.)	ESTIMATE
1	3.8 (57)		7	
2	4.6 (69)		14	
3	3.6 (54)		8	
4	4.5 (67.5)		11	
5	3.2 (48)		7	
6	4.5 (67.5)		8	
7	4.7 (70.5)		6	
8	4.7 (67.5)		12	

TASK 3

	REAL TIME	ESTIMATED TIME (MIN.)
a		
b		

took to make the trip. We will then ask you to turn around and drive back the same way we came, and again ask you to estimate the time. Please obey the speed limit signs at all times. Are there any questions?

TASK 4 Car Following - Voluntary Occlusion

Subject Instructions:

The lead car will be traveling ahead of you at a constant speed. We would like you to drive behind the lead car as if you are on a two-lane highway attempting to pass but were unable to do so because of oncoming traffic in the left lane. Try to hold the car at that distance as well as you can. In addition, we would like you to drive with your eyes closed as much as possible, but make sure you keep the car within the lane markers. As before, the safety man, seated next to you, will tell you to "open" if it becomes necessary; but you should not rely on him at all. If you are performing the task correctly and keeping the car within the white lane markers, he will not have to say "open". Are there any questions?

TASK 5 Open Road - Normal

Subject Instructions:

Please drive the car in your normal manner at about 50 or 60 mph. Please stay in the right lane. Are there any questions?

TASK 6 Car Following - Normal

Subject Instructions:

The lead car will be traveling ahead of you at a constant speed. We would like you to drive behind the lead car (as if you were on a two-lane highway attempting to pass but were unable to do so because of oncoming traffic in the left lane) and try to hold this car at that distance as well as you can.

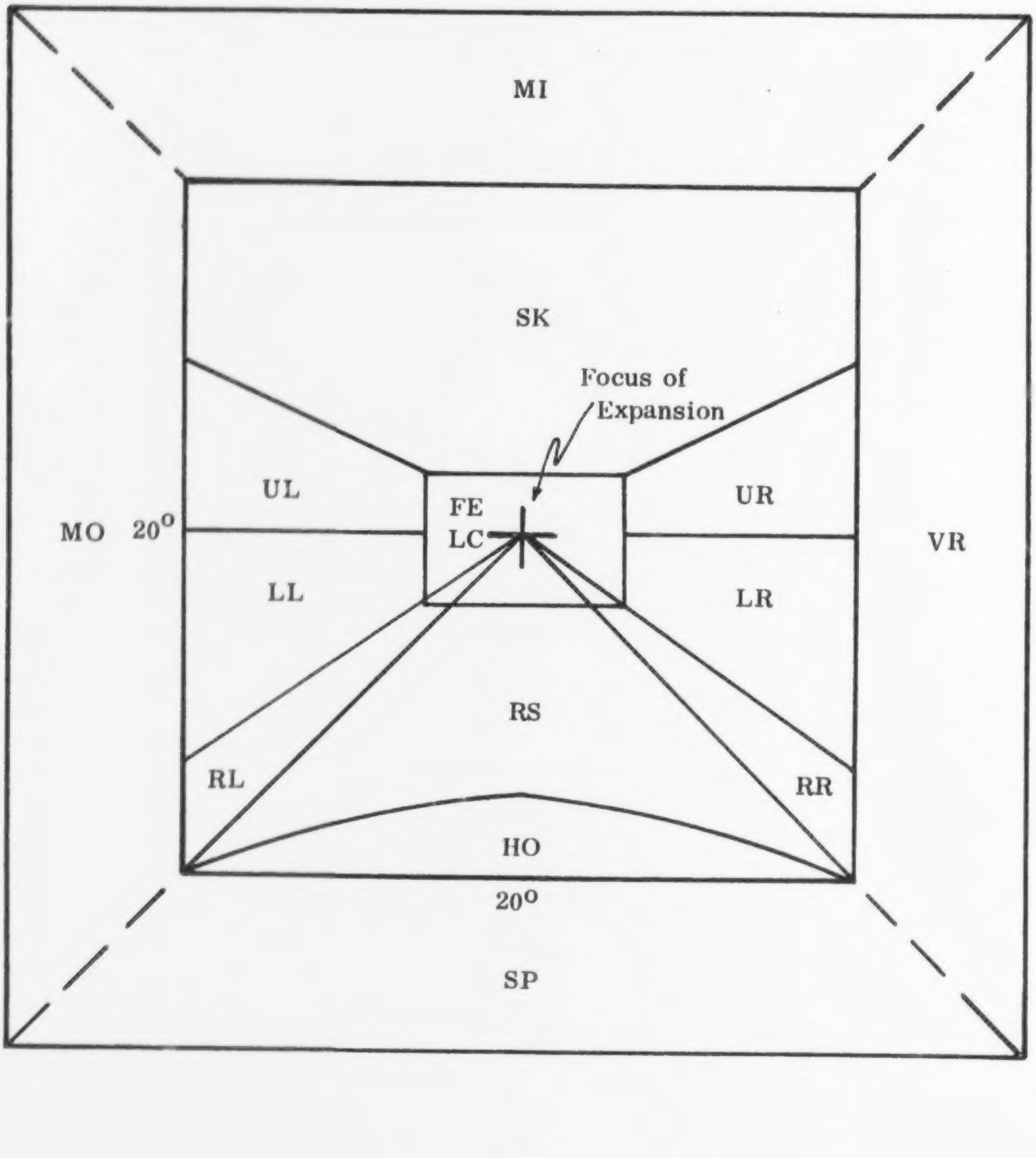
TASK 7 Signing

a) Please drive in your normal manner and exit at Rt. 161. Are there any questions?

b) Please drive in your normal manner and exit at Hudson Street. Are there any questions?

APPENDIX C

GRID FOR OBJECT CODE ANALYSIS


MI
SK
Focus of Expansion
UL
FE
UR
MO
20°
LC
VR
LL
LR
RS
RL
RR
HO
20°
SP

Object Code Analysis for Task 5 and Task 6

MO - rearview mirror outside
MI - rearview mirror inside
SP - speedometer
VR - out of view (right)
SK - sky
UL - upper left scenery
LL - lower left scenery
UR - upper right scenery
LR - lower right scenery
HO - hood of car
RL - road left
RR - road right
BL - blink
RS - road straight ahead

(task 5) FE* - 3° x 6° block centered on focus of expansion
(task 6) LC* - lead car

- -

Miscellaneous Codes

NR - no reduction (not relevant to task)
PL - car passing on left
PR - car passing on right
CA - car ahead

APPENDIX D

HEALTH QUESTIONNAIRE

Date ________

This information is strictly confidential

Print Your Name ________________________ Your Home Address ________________________

How Old Are You? ________________ Circle If You Are . . Single, Married, Widowed, Separated, Divorced.

Circle the Highest Year You Reached In School | 1 2 3 4 5 6 7 8 | Elementary School | 1 2 3 4 | High | 1 2 3 4 | College

What Is Your Occupation? ________________

Directions: This questionnaire is for *MEN ONLY.*
If you can answer **YES** to the question asked, put a circle around the (Yes)
If you have to answer **NO** to the question asked, put a circle around the (No)
Answer all questions. If you are not sure, guess.

A

1. Do you need glasses to read? .... Yes No
2. Do you need glasses to see things at a distance? .... Yes No
3. Has your eyesight often blacked out completely? .... Yes No
4. Do your eyes continually blink or water? .... Yes No
5. Do you often have bad pains in your eyes? .... Yes No
6. Are your eyes often red or inflamed? .... Yes No
7. Are you hard of hearing? .... Yes No
8. Have you ever had a bad running ear? .... Yes No
9. Do you have constant noises in your ears? .... Yes No

B

10. Do you have to clear your throat frequently? Yes No
11. Do you often feel a choking lump in your throat? .... Yes No
12. Are you often troubled with bad spells of sneezing? .... Yes No
13. Is your nose continually stuffed up? .... Yes No
14. Do you suffer from a constantly running nose? .... Yes No
15. Have you at times had bad nose bleeds? .... Yes No
16. Do you often catch severe colds? .... Yes No
17. Do you frequently suffer from heavy chest colds? .... Yes No
18. When you catch a cold, do you always have to go to bed? .... Yes No
19. Do frequent colds keep you miserable all winter? .... Yes No
20. Do you get hay fever? .... Yes No
21. Do you suffer from asthma? .... Yes No
22. Are you troubled by constant coughing? .... Yes No
23. Have you ever coughed up blood? .... Yes No
24. Do you sometimes have severe soaking sweats at night? .... Yes No
25. Have you ever had a chronic chest condition? Yes No
26. Have you ever had T.B. (Tuberculosis)? .... Yes No
27. Did you ever live with anyone who had T.B.? Yes No

C

28. Has a doctor ever said your blood pressure was too *high?* .... Yes No
29. Has a doctor ever said your blood pressure was too *low?* .... Yes No
30. Do you have pains in the heart or chest? .... Yes No
31. Are you often bothered by thumping of the heart? .... Yes No
32. Does your heart often race like mad? .... Yes No
33. Do you often have difficulty in breathing? .... Yes No
34. Do you get out of breath long before anyone else? .... Yes No
35. Do you sometimes get out of breath just sitting still? .... Yes No
36. Are your ankles often badly swollen? .... Yes No
37. Do cold hands or feet trouble you even in hot weather? .... Yes No
38. Do you suffer from frequent cramps in your legs? .... Yes No
39. Has a doctor ever said you had heart trouble? Yes No
40. Does heart trouble run in your family? .... Yes No

OPEN TO NEXT PAGE

D

41. Have you lost more than half your teeth? Yes No

42. Are you troubled by bleeding gums? Yes No

43. Have you often had severe toothaches? Yes No

44. Is your tongue usually badly coated? Yes No

45. Is your appetite always poor? Yes No

46. Do you usually eat sweets or other food between meals? Yes No

47. Do you always gulp your food in a hurry? Yes No

48. Do you often suffer from an upset stomach? Yes No

49. Do you usually feel bloated after eating? Yes No

50. Do you usually belch a lot after eating? Yes No

51. Are you often sick to your stomach? Yes No

52. Do you suffer from indigestion? Yes No

53. Do severe pains in the stomach often double you up? Yes No

54. Do you suffer from constant stomach trouble? Yes No

55. Does stomach trouble run in your family? Yes No

56. Has a doctor ever said you had stomach ulcers? Yes No

57. Do you suffer from frequent loose bowel movements? Yes No

58. Have you ever had severe bloody diarrhea? Yes No

59. Were you ever troubled with intestinal worms? Yes No

60. Do you constantly suffer from bad constipation? Yes No

61. Have you ever had piles (rectal hemorrhoids)? Yes No

62. Have you ever had jaundice (yellow eyes and skin)? Yes No

63. Have you ever had serious liver or gall bladder trouble? Yes No

E

64. Are your joints often painfully swollen? Yes No

65. Do your muscles and joints constantly feel stiff? Yes No

66. Do you usually have severe pains in the arms or legs? Yes No

67. Are you crippled with severe rheumatism (arthritis)? Yes No

68. Does rheumatism (arthritis) run in your family? Yes No

69. Do weak or painful feet make your life miserable? Yes No

70. Do pains in the back make it hard for you to keep up with your work? Yes No

71. Are you troubled with a serious bodily disability or deformity? Yes No

F

72. Is your skin very sensitive or tender? Yes No

73. Do cuts in your skin usually stay open a long time? Yes No

74. Does your face often get badly flushed? Yes No

75. Do you sweat a great deal even in cold weather? Yes No

76. Are you often bothered by severe itching? Yes No

77. Does your skin often break out in a rash? Yes No

78. Are you often troubled with boils? Yes No

G

79. Do you suffer badly from frequent severe headaches? Yes No

80. Does pressure or pain in the head often make life miserable? Yes No

81. Are headaches common in your family? Yes No

82. Do you have hot or cold spells? Yes No

83. Do you often have spells of severe dizziness? Yes No

84. Do you frequently feel faint? Yes No

85. Have you fainted more than twice in your life? Yes No

86. Do you have constant numbness or tingling in any part of your body? Yes No

87. Was any part of your body ever paralyzed? Yes No

88. Were you ever knocked unconscious? Yes No

89. Have you at times had a twitching of the face, head or shoulders? Yes No

90. Did you ever have a fit or convulsion (epilepsy)? Yes No

91. Has anyone in your family ever had fits or convulsions (epilepsy)? Yes No

92. Do you bite your nails badly? Yes No

93. Are you troubled by stuttering or stammering? Yes No

94. Are you a sleep walker? Yes No

95. Are you a bed wetter? Yes No

96. Were you a bed wetter between the ages of 8 and 14? Yes No

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H

97. Have you ever had anything seriously wrong with your genitals (privates)? Yes No

98. Are your genitals often painful or sore? Yes No

99. Have you ever had treatment for your genitals? Yes No

100. Has a doctor ever said you had a hernia (rupture)? Yes No

101. Have you ever passed blood while urinating (passing water)? Yes No

102. Do you have trouble starting your stream when urinating? Yes No

103. Do you have to get up every night and urinate? Yes No

104. During the day, do you usually have to urinate frequently? Yes No

105. Do you often have severe burning pain when you urinate? Yes No

106. Do you sometimes lose control of your bladder? Yes No

107. Has a doctor ever said you had kidney or bladder disease? Yes No

I

108. Do you often get spells of complete exhaustion or fatigue? Yes No

109. Does working tire you out completely? Yes No

110. Do you usually get up tired and exhausted in the morning? Yes No

111. Does every little effort wear you out? Yes No

112. Are you constantly too tired and exhausted even to eat? Yes No

113. Do you suffer from severe nervous exhaustion? Yes No

114. Does nervous exhaustion run in your family? Yes No

J

115. Are you frequently ill? Yes No

116. Are you frequently confined to bed by illness? Yes No

117. Are you always in poor health? Yes No

118. Are you considered a sickly person? Yes No

119. Do you come from a sickly family? Yes No

120. Do severe pains and aches make it impossible for you to do your work? Yes No

121. Do you wear yourself out worrying about your health? Yes No

122. Are you always ill and unhappy? Yes No

123. Are you constantly made miserable by poor health? Yes No

K

124. Did you ever have scarlet fever? Yes No

125. As a child, did you have rheumatic fever, growing pains or twitching of the limbs? Yes No

126. Did you ever have malaria? Yes No

127. Were you ever treated for severe anemia (thin blood)? Yes No

128. Were you ever treated for "bad blood" (venereal disease)? Yes No

129. Do you have diabetes (sugar disease)? Yes No

130. Did a doctor ever say you had a goiter (in your neck)? Yes No

131. Did a doctor ever treat you for tumor or cancer? Yes No

132. Do you suffer from any chronic disease? Yes No

133. Are you definitely *under* weight? Yes No

134. Are you definitely *over* weight? Yes No

135. Did a doctor ever say you had varicose veins (swollen veins) in your legs? Yes No

136. Did you ever have a serious operation? Yes No

137. Did you ever have a serious injury? Yes No

138. Do you often have small accidents or injuries? Yes No

L

139. Do you usually have great difficulty in falling asleep or staying asleep? Yes No

140. Do you find it impossible to take a regular rest period each day? Yes No

141. Do you find it impossible to take regular daily exercise? Yes No

142. Do you smoke more than 20 cigarettes a day? Yes No

143. Do you drink more than six cups of coffee or tea a day? Yes No

144. Do you usually take two or more alcoholic drinks a day? Yes No

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M

145. Do you sweat or tremble a lot during examinations or questioning? Yes No

146. Do you get nervous and shaky when approached by a superior? Yes No

147. Does your work fall to pieces when the boss or a superior is watching you? Yes No

148. Does your thinking get completely mixed up when you have to do things quickly? Yes No

149. Must you do things very slowly in order to do them without mistakes? Yes No

150. Do you always get directions and orders wrong? Yes No

151. Do strange people or places make you afraid? Yes No

152. Are you scared to be alone when there are no friends near you? Yes No

153. Is it always hard for you to make up your mind? Yes No

154. Do you wish you always had someone at your side to advise you? Yes No

155. Are you considered a clumsy person? Yes No

156. Does it bother you to eat anywhere except in your own home? Yes No

N

157. Do you feel alone and sad at a party? Yes No

158. Do you usually feel unhappy and depressed? Yes No

159. Do you often cry? Yes No

160. Are you always miserable and blue? Yes No

161. Does life look entirely hopeless? Yes No

162. Do you often wish you were dead and away from it all? Yes No

O

163. Does worrying continually get you down? Yes No

164. Does worrying run in your family? Yes No

165. Does every little thing get on your nerves and wear you out? Yes No

166. Are you considered a nervous person? Yes No

167. Does nervousness run in your family? Yes No

168. Did you ever have a nervous breakdown? Yes No

169. Did anyone in your family ever have a nervous breakdown? Yes No

170. Were you ever a patient in a *mental* hospital (for your nerves)? Yes No

171. Was anyone in your family ever a patient in a *mental* hospital (for their nerves)? Yes No

P

172. Are you extremely shy or sensitive? Yes No

173. Do you come from a shy or sensitive family? Yes No

174. Are your feelings easily hurt? Yes No

175. Does criticism always upset you? Yes No

176. Are you considered a touchy person? Yes No

177. Do people usually misunderstand you? Yes No

Q

178. Do you have to be on your guard even with friends? Yes No

179. Do you always do things on sudden impulse? Yes No

180. Are you easily upset or irritated? Yes No

181. Do you go to pieces if you don't constantly control yourself? Yes No

182. Do little annoyances get on your nerves and make you angry? Yes No

183. Does it make you angry to have anyone tell you what to do? Yes No

184. Do people often annoy and irritate you? Yes No

185. Do you flare up in anger if you can't have what you want right away? Yes No

186. Do you often get into a violent rage? Yes No

R

187. Do you often shake or tremble? Yes No

188. Are you constantly keyed up and jittery? Yes No

189. Do sudden noises make you jump or shake badly? Yes No

190. Do you tremble or feel weak whenever someone shouts at you? Yes No

191. Do you become scared at sudden movements or noises at night? Yes No

192. Are you often awakened out of your sleep by frightening dreams? Yes No

193. Do frightening thoughts keep coming back in your mind? Yes No

194. Do you often become suddenly scared for no good reason? Yes No

195. Do you often break out in a cold sweat? Yes No

The following information is strictly confidential and will only be used for this study.
(FEMALES ONLY)

S

196. Have you ever been pregnant? ....YES NO

197. Have you ever had a vaginal discharge?...............................YES NO

198. Have you ever been treated for a female disorder?....................YES NO

199. Have you ever had painful menstruation?..............................YES NO

200. Have you ever had irregular menstruation?............................YES NO

201. At what age did the onset of menstruation occur?______________________________

202. What are the intervals between periods?______________________________

203. What is the duration of the periods?______________________________

204. What was the date of the last period?______________________________

205. What type(s) of contraceptive are you presently using?____________________

____

00

This form is strictly confidential and will be used only for purposes of this study.

PATIENT OR VOLUNTEER

CONSENT TO SPECIAL TREATMENT OR PROCEDURES

Date ____________________ Time ______ A.M. P.M.

I authorize the performance upon ______________________________
(myself)

of the following treatment or procedure: oral administration of ETOH (alcohol) and inhalation of carbon monoxide in air sufficient to produce blood levels of up to 0.06 percent alcohol, and 20 percent carboxyhemoglobin (COHb): withdrawal of blood to evaluate alcohol and COHb levels, and evaluation of performance in the laboratory, and in an instrumented motor vehicle on the highway under controlled conditions and with appropriate safety precautions.

This treatment or procedure is to be performed by, or under the direction of Dr. Charles E. Billings, M.D. He is authorized to use the services of others in the performance of this procedure as he deems necessary.

The nature and purpose of the procedure or treatment, possible alternative methods of treatment, the known risks involved, and the possibility of complications have been explained to me, and I understand them. I fully understand that the procedure or treatment to be performed is experimental and unproven by medical experience, and that the consequences are unpredictable. No guarantee or assurance has been given by anyone as to the results that may be obtained. I further understand that I may withdraw from the procedure at any time.

I understand that the known risks are:

Euphoria due to alcohol,

Local discomfort following blood withdrawal,

Headaches due to combined effects of carbon monoxide and alcohol,

Nausea due to combined effects of carbon monoxide and alcohol.

Signed: ______________________________
(patient or person authorized to consent for patient)

Witness: ______________________

Witness: ______________________
(Investigator)

APPENDIX E

SUBJECT COHb LEVELS AND BAL's

Table E.1

COHb Levels and BAL's of Subjects--Phase 1

Sub-ject	Target Levels		COHb Readings						Mean		BAL Readings				Mean	
	BAL	COHb	1	2	3	4	5	6	COHb	S. D.	1	2	3	4	BAL	S. D.
S1	LO	2%	2.8	2.5	2.8	3.2	3.8	4.1	3.20	0.069	--	--	--	--	--	--
		8%	7.6	8.4	8.6	8.5	8.0	8.7	8.30	0.419	--	--	--	--	--	--
	HI	2%	2.5	4.6	5.0	4.7	4.6	4.2	4.26	0.902	.046	.046	.038	.043	.043	.0037
		8%	8.0	8.3	8.2	8.4	8.3	7.6	8.13	0.294	.042	.045	.038	-	.0416	.0035
S2	LO	2%	2.5	3.2	3.7	3.8	3.9	--	3.42	0.581	--	--	--	--	--	--
		8%	7.0	8.2	8.1	7.5	7.7	6.9	7.56	0.543	--	--	--	--	--	--
	HI	2%	3.1	4.5	4.3	4.3	4.9	4.7	4.30	0.632	040	.040	--	.040	.04	0.0
		8%	7.4	6.2	6.7	4.5	5.4	5.2	5.9	0.356	.040	.042	.030	.020	.033	.01
S3	LO	2%	2.5	4.5	4.2	4.8	4.8	4.3	4.18	0.861	--	--	--	--	--	--
		8%	7.5	8.1	8.1	9.1	9.2	--	8.40	0.728	--	--	--	--	--	--
	HI	2%	3.7	--	2.4	--	2.7	--	2.93	0.681	.050	--	.041	.045	.045	.0045
		8%	7.0	6.1	6.3	6.0	6.4	7.2	6.50	0.489	.035	.054	.046	.035	.042	.0092
S4	LO	2%	3.1	4.8	4.1	4.6	3.9	--	4.10	0.667	--	--	--	--	--	--
		8%	7.6	7.6	7.6	--	7.7	7.6	7.62	0.045	--	--	--	--	--	--
	HI	2%	2.0	3.3	3.6	3.4	3.6	4.3	3.36	0.755	.038	.050	.042	.025	.038	.01
		8%	8.2	6.9	7.6	6.2	7.5	6.1	7.08	0.833	.048	.048	.060	.054	.0525	.0057

COHb Readings: 1, 6 before and after road tests.
2, 3 at first refresh stop, and 4, 5 at second refresh stop.
BAL Readings: 1 and 4 before and after road test, 2 and 3 at 1st and 2nd refresh stops.

Table E. 2

COHb Levels and BAL's of Subjects-- Phase 2

Sub-ject	Target Levels										BAL Readings					
	BAL	COHb	1	2	3	4	5	6	Mean COHb	S. D.	1	2	3	4	Mean BAL	S. D.
S5	LO	8%	8.6	7.7	8.5	8.2	7.3	6.8	7.85	.712	--	--	--	--	--	--
		12%	11.0	12.1	12.3	11.6	12.7	12.1	11.97	.592	--	--	--	--	--	--
	HI	8%	8.5	6.2	--	--	--	--	7.35	--	.045	.045	.038	--	.042	.004
		12%	12.6	10.9	12.3	--	--	--	11.93	.907	--	.040	.038	--	.039	--
S6	LO	8%	7.0	7.8	8.5	7.7	7.6	6.8	7.57	.610	--	--	--	--	--	--
		12%	12.0	15.0	15.4	14.8	13.8	13.5	14.08	1.25	--	--	--	--	--	--
	HI	8%	7.6	6.6	7.7	6.4	7.3	6.2	6.97	.647	.035	.050	.050	.042	.044	.007
		12%	11.6	12.5	13.1	12.5	12.7	--	12.48	.549	.045	.041	.038	.041	.041	.0028
S7	LO	8%	8.5	8.6	9.1	8.2	8.4	7.8	8.43	.432	--	--	--	--	--	--
		12%	13.2	12.3	12.7	10.4	11.4	--	12.0	1.11	--	--	--	--	--	--
	HI	8%	7.9	7.2	7.3	6.7	7.6	6.5	7.20	.529	.042	.050	.042	.038	.043	.005
		12%	11.6	10.1	11.2	10.0	12.7	11.1	11.12	1.00	--	.043	.040	--	.0415	--
S8	LO	8%	8.4	7.4	7.6	7.0	7.0	6.8	7.36	.585	--	--	--	--	--	--
		12%	10.4	9.5	9.5	10.2	10.8	9.6	10.00	.5477	--	--	--	--	--	--
	HI	8%	8.1	5.9	8.9	8.2	8.0	7.8	7.81	1.01	.052	.042	.048	.035	.044	.0074
		12%	12.5	9.0	8.2	8.6	10.6	12.3	10.20	1.88	.045	.053	.036	.022	.039	.013

COHb Readings: 1, 6 before and after road tests.
2, 3 at first refresh stop, and 4, 5 at second refresh stop.
BAL Readings: 1 and 4 before and after road test, 2 and 3 at 1st and 2nd refresh stops.

Table E. 3

COHb Levels and BAL's of Subjects--Phase 3

Sub-	Target Levels		COHb Readings						Mean		BAL Readings				Mean	
ject	BAL	COHb	1	2	3	4	5	6	COHb	S. D.	1	2	3	4	BAL	S. D.
S9	LO	2%	1.9	2.0	2.5	2.4	2.0	--	2.16	.27	--	--	--	--	--	--
	HI	12%	11.8	10.8	10.1	10.5	10.6	--	10.76	.635	.03	.035	.045	.034	.036	.0063
S10	LO	2%	2.1	2.5	2.9	2.1	2.7	--	2.46	.357	--	--	--	--	--	--
	HI	12%	10.7	10.6	12.5	11.2	11.7	9.7	11.06	.968	.034	.044	.051	.043	.043	.0069
S11	LO	2%	1.8	1.6	2.6	2.4	1.5	2.6	2.08	.507	--	--	--	--	--	--
	HI	12%	9.9	9.0	10.5	9.8	9.8	--	9.8	.533	.049	.042	.045	.029	.041	.0086
S12	LO	2%	1.4	1.9	1.8	2.1	2.4	2.1	1.95	.339	--	--	--	--	--	--
	HI	12%	9.5	9.9	11.9	10.8	11.1	11.4	10.76	0.911	.034	.092	.051	.036	.040	.0076

COHb Readings: 1, 6, before and after road tests.
2, 3 at first refresh stop, and 4, 5 at second refresh stop.
BAL Readings: 1 and 4 before and after road test, 2 and 3 at 1st and 2nd refresh stops.

APPENDIX F

HEADWAY CALIBRATION CURVE

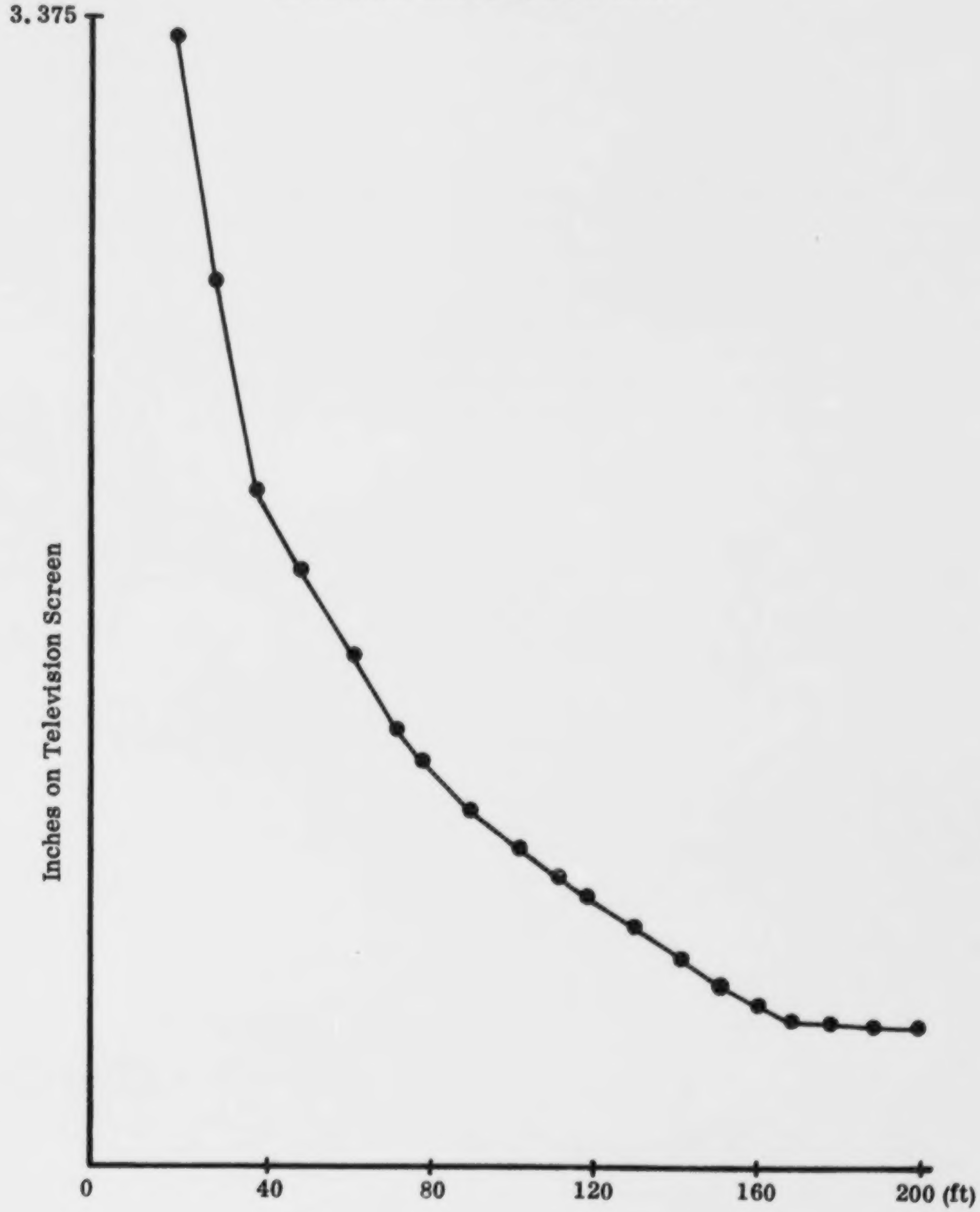

Figure F. 1.--Headway Calibration Curve for Headway Determination from Video Screen

APPENDIX G

LABORATORY TESTS: DESIGN AND RESULTS

G.1 Design of Experiments

The objective of the laboratory tests was to investigate the interactive effects of alcohol and CO on test performance. The tests used were Spatial Relations, Mirror Tracing, Brightness Discrimination and Rail Walk. For the descriptions of these tests the reader is referred to the Final Report of Project CRC-APRAL CAPM-9-69 (pages 27-31). These tests were conducted with subjects different from road test subjects during different days. The experiments were carried out in two phases. Phase A was a 6x6 Latin square and Phase B was a 4x4 Latin square design. (See Figure G.1).

Phase A DAYS

Subjects	D1	D2	D3	D4	D5	D6
S13	T1	T2	T3	T4	T5	T6
S14	T2	T3	T4	T5	T6	T1
S15	T3	T4	T5	T6	T1	T2
S16	T4	T5	T6	T1	T2	T3
S17	T5	T6	T1	T2	T3	T4
S18	T6	T1	T2	T3	T4	T5

Nominal COHb

	0	7	12
0 BAL	T1	T2	T3
.05 BAL	T4	T5	T6

Phase B DAYS

Subjects	D1	D2	D3	D4
S19	T7	T8	T9	T10
S20	T8	T9	T10	T7
S21	T9	T10	T7	T8
S22	T10	T7	T8	T9

Nominal BAL

0	.02	.05	.08
T7	T8	T9	T10

Figure G.1--Laboratory Experimental Design

Phase A: The three factors for this design were subjects, days, and treatments. Each of the factors was used at six levels. Six treatment levels were obtained by combining the two BAL levels (0, .05%) and three nominal COHb levels (0, 7, and 12%).

Phase B: In Phase B the same factors were used, but the treatments were BAL only. The levels were 0, .02, .05, .08% BAL. In this study the subjects represented various types of drinkers (non-drinker, social drinker and heavy drinker).

The procedure that was followed required the subject to be exposed or dosed to attain the appropriate treatment level prior to testing (see Figure 2.4). At a prescribed time the tests began, first Spatial Relations, then Mirror Tracing, Brightness Discrimination and Rail Walk. These tests were conducted the same for all subjects. The subjects acted as their own controls. For subject instructions, refer to Section G.2.

After testing, the subjects of Phase A were given oxygen to detoxify. Phase B subjects were kept at the laboratory for an hour to allow the body to metabolize the alcohol. This procedure was repeated for as many days as the individual design required. Section G.3 presents the results from analyses. Table G.1 gives the actual COHb levels and BAL's attained during experiments.

G.2 Subject Instructions

Mirror-Drawing; Star-Tracing - The test that you see before you is the star-tracing test. The ready position for this test is to be seated. Facing the mirror box, place a 3-inch pencil in your normal writing hand. Place the pencil point on the red line that crosses the right side of the star. At the signal of "GO!", trace the outline of the star going in the direction of the arrow. Work as rapidly as you can, but try to keep between the two red lines and do not lift your pencil until the tracing has been completed.

I repeat: Follow the tracing of the star, keep between the lines, do not lift your pencil until the star has been completed. Please do not talk during the test.

Please assume the ready position.

GO!

Brightness Discrimination Test - Your next test is called a brightness discrimination test. The ready position for this test is to be seated facing the color

Table G.1

Laboratory Tests -- Subject COHb Levels and BALs

Phase A

	Nominal % COHb Level		
	0	7	12
Pre-exposure	1.8 (0.48)	1.9 (0.36)	1.7 (0.46)
Post exposure	1.8 (0.62)	7.6 (0.89)	11.6 (0.94)
Test complete	1.8 (0.51)	6.9 (1.11)	10.7 (0.75)

	% BAL	
	Mean	S. D.
Post exposure	0.046	0.004
End testing	0.034	0.003
Avg. during test	0.041	0.007

Phase B

	% BAL		
	0.02	0.05	0.08
Post exposure	.018 (.003)	.049 (.002)	.078 (.005)
End testing	.011 (.002)	.035 (.003)	.058 (.008)
Avg. during test	.014 (.004)	.042 (.007)	.068 (.012)

Values in brackets refer to S. D.

light box mounted on the wall. Place the reostat control in your operating hand and turn the knob counterclockwise. Soon after, two green lights will appear. Your reostat will control the left light. Your task is to match up the apparent brightness of the left light with that of the right by adjusting the reostat knob until you are satisfied they are matched. Then give a verbal acknowledgment of "OK". Do not move the reostat knob until the experimenter tells you to turn the knob all the way down. This procedure will be repeated three times for the colors green, red, yellow and white.

Rail Walking - The rail walking test consists of a 10-foot length of 5/8-inch plank. Your task is to walk the rail as fast and as far as you can, unassisted. The ready position is to place your lead foot on the rail and at the signal of "GO" walk the rail, heel to toe. You will be given one practice trial and the next three will be recorded.

Please assume the ready position.

GO!

Spatial Relations Test - The test that you see before you is called the Spatial Relations test. The ready position for this test is to stand facing the board and pieces located on the table with your hands at your side. Put the blocks in their proper places on the board. They fit easily; do not force any of them. Use one hand and the same hand throughout the tests. You may have to turn some of the blocks around, but do not turn any of them over. Keep the painted side of the blocks up. Go as fast as you can and put all of the blocks in the board. Please do not talk during the test.

Please assume the ready position.

GO!

G.3 Results of Laboratory Testing

Subject Symptoms and Observed Responses - Each of the subjects was questioned immediately upon leaving the exposure chamber about the presence or absence of symptoms that may be related temporarily to CO exposure. These symptoms included headache, nausea, fatigue, dizziness, and irritability. Seventy-five percent of the total subjects complained of one or more of the five symptoms. The symptoms were reported at either high COHb treatment levels or a combination of high COHb and BAL. The most complaints came from the three women that participated in the project. In order of most frequent occurrence, dizziness, fatigue, headache, and then nausea was reported. No subject reported irritability at any time during the experimentation. These findings seem to agree with what is expected from the literature.

Spatial Relations - The spatial relations test showed no significance from the effects of CO or CO/ETHANOL. This indicates that there were no synergistic or antagonistic effects between CO and ETHANOL for this test. However, there was a total subject significance found for ETHANOL in this study.

Mirror Tracing - The mirror tracing test did not show any significance for any of the parameters of the design.

Brightness Discrimination - The brightness discrimination test showed significance for the color yellow under ETHANOL treatment and significance for the color white for CO/ETHANOL treatments.

Rail Walk - The rail walk test, in which every subject participated, indicated significance for ETHANOL treatments.

Tables G.2 through G.9 indicate the (F) values for CO/ETHANOL laboratory tasks.

Conclusion

In general, strong correlations between performance on simple laboratory tasks and COHb/BAL levels were not observed. However, a performance degradation was indicated at some BAL's. The ETHANOL study did give some indication that 0.05 BAL might not be close enough to the threshold level. Therefore, a BAL of 0.08 might have provided a more significant decrement in the performance of the subjects used in the road and laboratory CO/ETHANOL treatments.

Table G. 2

Summary of (F) Values from Analysis of Variance from Combined Test Data

CO/ETHANOL

TEST NO.	TEST	CO	ETHANOL	CO x ETHANOL
		←	F	→
1	STAR TRACING	0.77 +	0.19 -	0.69
2	SPATIAL RELATIONS			
	BOARD A	0.03	0.09	0.06
	BOARD B	0.91	0.42	0.06 -
	BOARD C	0.24	0.12	0.05
	BOARD D	0.03	0.08	0.05
3	BDT ΔV			
	RED	0.47 +	0.09 +	0.67 -
	GREEN	0.42 -	0.05 -	1.90 +
	YELLOW	1.02 -	1.96 +	1.54 -
	WHITE	0.47 +	7.35**+	1.02 +
4	BDT RATIO			
	RED	0.63 +	0.20 +	0.78 -
	GREEN	0.64 -	0.19 -	2.12 +
	YELLOW	1.27 -	3.69 +	0.95 -
	WHITE	0.52 +	4.99 * +	1.28 +
5	RAIL WALK			
	DISTANCE	0.82 +	2.79 -	0.19
	TIME	1.23 -	0.01	0.04 -
	FT/SEC	0.52 +	2.63 -	0.41 +

* $p \leq .10$
** $p \leq .05$
BDT = Brightness Discrimination Test
+ increasing trend
- decreasing trend

Table G. 3

Summary of (F) Values from Analysis of Variance from Combined Test Data

CO/Ethanol

Test No.	Test	Board or Color	CO	ETOH	Board or Color x CO	Board or Color x Ethanol	CO x Ethanol	Board or Color x COx Ethanol
6	Spatial Relations	0. 33	1. 87	0. 29	0. 45	0. 93	0. 07	0. 35
7	BDTΔV	0. 90	0. 15 -	1. 46 +	0. 82	0. 39	0. 95	0. 91
8	BDT Ratio	0. 87	0. 17 -	2. 95 +	0. 88	0. 66	1. 38	1. 08

Summary of (F) Values from Analysis of Variance from Combined Test Data

Ethanol

Test No.	Test	Mean	Board or Color	Ethanol	Board or Color x Ethanol
9	Spatial Relations	975. 60	17. 89** +	13. 55** -	5. 02** -
10	BDT Δ V	255. 71	1. 05	2. 02	1. 63
11	BDT Ratio	49. 54	0. 80	1. 99	1. 69

* $p \leq .10$
** $p \leq .05$
+ increasing trend
- decreasing trend

Table G. 4

Summary of (F) Values from Analysis of Variance from Combined Test Data

Ethanol

Test No.	Test	Ethanol
12	Star Tracing	0. 82 -
13	Spatial Relations	
	Board A	0. 37 -
	Board B	4. 49** -
	Board C	2. 58 -
	Board D	1. 52 -
14	BDT Δ V	
	Red	0. 22 +
	Green	0. 55 +
	Yellow	3. 39* -
	White	1. 90
15	BDT Ratio	
	Red	0. 37 +
	Green	0. 46
	Yellow	3. 35* -
	White	1. 90 -
16	Rail Walk	
	Distance	5. 45** -
	Time	3. 32* -
	Ft. /Sec.	4. 10**+

* $p \leq .10$	+ increasing trend
** $p \leq .05$	- decreasing trend

Table G.5

Duncan New Multiple Range Test

		BAL		
Test	0.00	0.02	0.05	0.08
Rail Walk (Distance)		** ----	----	---- **
			**----	---- **
	* ----	----	----	---- *
		* ----	----	---- *
			* ----	---- *
BDT ΔV & Ratio (Yellow)		** ----	---- **	
	* ----	----	---- *	
		* ----	---- *	
Spatial Relations Board B	** ----	----	----	---- **
	* ----	----	----	---- *
			* ----	---- *
Spatial Relations All Boards	** ----	----	----	----**
	* ----	----	----	---- *
		* ----	----	---- *
			* ----	---- *

** p = < .05
* p = < .10

(asterisks connected by dashes show significance between BAL)

Table G. 6

Critical (F) Values for Tests 1-5

Source	d. f	Critical (F) Values	
		p = .05	p = .10
CO	2/10	4.10	2.92
Ethanol	1/5	6.61	4.06
CO x Ethanol	2.10	4.10	2.92

Table G. 7

Critical (F) Values for Tests 6-8

Source	d. f.	Critical (F) Values	
		p = .05	p = .10
Board or Color	3/15	3.29	2.49
CO	2/10	4.10	2.92
Ethanol	1/5	6.61	4.06
Board or Color x CO	6/30	2.42	1.98
Board or Color x Ethanol	3/15	3.29	2.49
CO x Ethanol	2/10	4.10	2.92
Board or Color x CO	6/30	2.42	1.98

Table G. 8

Critical (F) Values for Tests 9-11

Source	d. f.	Critical (F) Values	
		p = .05	p = .10
Board or Color	3/9	3.86	2.81
Ethanol	3/9	3.86	2.81
Board or Color x Ethanol	9/27	2.25	1.87

Table G. 9

Critical (F) Values for Tests 12-16

Source	d. f.	Critical (F) Values	
		p = .05	p = .10
Ethanol	3/9	3.86	2.81

APPENDIX H

ANOVA TABLES FOR THE PERFORMANCE MEASURES IN ROAD EXPERIMENTS

ANOVA NO.	PERFORMANCE MEASURE
1	Time Estimation Error
2	Velocity Estimation Error
3	Steering Wheel Reversals/Minute (Open Road)
4	Steering Wheel Reversals/Minute (Curve Task)
5	Peak Lateral Acceleration in 'g' (Curve Task)
6	Velocity Reduction in Curves
7	Mean Headway (Car Following - Normal Vision)
8	S. D. Headway (Car Following - Normal Vision)
9	Mean Headway (Car Following - Voluntary Occlusion)
10	S. D. Headway (Car Following - Voluntary Occlusion)
11	Mean Open Time (Open Road - Voluntary Occlusion)
12	S. D. Open Time (Open Road - Voluntary Occlusion)
13	Mean Closed Time (Open Road - Voluntary Occlusion)
14	S. D. Closed Time (Open Road - Voluntary Occlusion)
15	Percent of Total Time Closed (Open Road - Voluntary Occlusion)
16	Mean Open Time (Car Following - Voluntary Occlusion)
17	S. D. Open Time (Car Following - Voluntary Occlusion)
18	Mean Closed Time (Car Following - Voluntary Occlusion)
19	S. D. Closed Time (Car Following - Voluntary Occlusion)
20	Percent of Total Time Closed (Car Following - Voluntary Occlusion)
21	Perceptual Uncertainity (Open Road - Voluntary Occlusion)
22	Perceptual Uncertainty (Car Following - Voluntary Occlusion)
23	Mean Time in FE (Open Road - Object Code)
24	S. D. of Time in FE (Open Road - Object Code)
25	Percent of Total Time in FE (Open Road - Object Code)
26	Mean Time in LC (Car Following - Object Code)
27	S. D. of Time in LC (Car Following - Object Code)
28	Percent of Total Time in LC (Car Following - Object Code)
29	T used (Sign Reading)
30	T_f (Sign Reading)

ANOVA 1

Task: Time Estimation Error

Source	Phase 1				Phase 2				Phase 3			
	d.f.	Ms	F	p	d.f.	Ms	F	p	d.f.	Ms	F	p
Subject	3	0.4693	0.54		3	5.1806	10.79	p < 0.01	3	24.95	9.33	p<0.05
Day	3	1.1013	1.28		3	0.4879	1.01					
Level	3	0.2694	0.31		3	0.3498	0.72		1	16.15	6.04	p < 0.09
(BAL)	(1)	0.0676	0.07		(1)	[illegible]	1.71					
(CO)	(1)	0.7225	0.84		(1)	0.2197	0.45					
(CO x BAL)	(1)	0.0182	0.02		(1)	[illegible]	0.01					
Error	6	0.8572			6	0.4801			3	2.67		
Total	15				15				7			

ANOVA 2

Task: Velocity Estimation Error (mph)

Source	Phase 1				Phase 2				Phase 3			
	d.f.	Ms	F	p	d.f.	Ms	F	p	d.f.	Ms	F	p
Subject	3	32.99	1.49		3	42.22	4.28	p < 0.10	3	86.21	10.82	p<0.05
Day	3	32.56	1.47		3	1.89	0.19					
Level	3	35.71	1.62		3	4.13	0.41		1	7.23	0.90	
(BAL)	(1)	40.16	1.82		(1)	6.71	0.68					
(CO)	(1)	1.17	0.05		(1)	5.14	0.52					
(CO x BAL)	(1)	65.81	2.98		(1)	0.53	0.05					
Error	6	22.04			5	9.86			3	7.96		
Total	15				14				7			

ANOVA 3

Task: Steering Wheel Reversals/minutes (open road)

Source	Phase 1				Phase 2				Phase 3			
	d.f.	Ms	F	p	d.f.	Ms	F	p	d.f.	Ms	F	p
Subject	3	189.16	6.84	p < 0.025	3	20.32	1.99		3	14.11	2.73	
Day	3	35.49	1.22		3	24.22	2.38					
Level	3	57.83	1.98		3	14.40	1.41		1	28.16	5.45	p<0.1
(BAL)	(1)	81.00	2.78		(1)	1.68	0.16					
(CO)	(1)	20.25	0.69		(1)	17.16	1.68					
(CO x BAL)	(1)	72.25	2.48		(1)	24.38	2.39					
Error	6	26.08			5	10.16			2	5.16		
Total	15				14				6			

Note: In Phase 3, with SS due to Subject and Day pooled with error, treatment is significant at p = 0.0627.

ANOVA 4

Task: Steering Wheel Reversals/minutes in curves

Source	Phase 1				Phase 2				Phase 3			
	d.f.	Ms	F	p	d.f.	Ms	F	p	d.f.	Ms	F	p
Subject	3	12.22	0.74		3	2.07	0.35		3	3.00	0.81	
Day	3	8.22	0.50		3	7.53	1.27					
Level	3	26.22	1.59		3	14.01	2.37		1	8.00	2.18	
(BAL)	(1)	1.56	0.09		(1)	0.58	0.09					
(CO)	(1)	76.58	4.66	p= 0.0725	(1)	15.54	2.63					
(CO x BAL)	(1)	0.56	0.03		(1)	25.92	4.39	p= 0.089				
Error	6	16.39			5	5.90			3	3.66		
Total	15				14				7			

Note: In Phase 1 with Day SS pooled with error, CO is significant at p = 0.0406

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ANOVA 5

Task: Peak Lateral Acceleration in 'g' in curves

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0.0035	0.32		3	0.00335	20.90	p< 0.005	3	0.00988	115.23	p< 0.001
Day	3	0.0049	0.45		3	0.00036	2.26					
Level	3	0.0075	0.69		3	0.00050	3.15					
(BAL)	(1)	0.0035	0.32		(1)	0.00057	3.57		1	0.00044	5.22	p= 0.10
(CO)	(1)	0.0124	1.14		(1)	0.00010	0.67					
(CO x BAL)	(1)	0.0067	0.61		(1)	0.00083	5.21	p= 0.07				
Error	6	0.0108			5	0.00016			3	0.00008		
Total	15				14				7			

ANOVA 6

Task: Velocity Reduction in Curves (mph)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	1.12	0.31		3	0.22	0.64		3	0.29	0.30	
Day	3	1.63	0.46		3	0.16	0.47					
Level	3	0.40	0.11		3	0.84	2.48					
(BAL)	(1)	0.44	0.12		(1)	2.07	6.08	p ≈ 0.05	1	3.96	4.06	
(CO)	(1)	0.69	0.19		(1)	0.32	0.93					
(CO x BAL)	(1)	0.08	0.03		(1)	0.14	0.41					
Error	6	3.56			6	0.34			3	0.97		
Total	15				15				7			

ANOVA 7

Task: Mean Headway in Feet--Car Following--Normal Vision

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	1123.90	4.66	p < 0.10	3	3350.30	4.96	p < 0.05	3	973.10	6.13	p < 0.10
Day	3	566.06	2.34		3	377.50	0.56					
Level	3	231.06	0.95		3	265.90	0.39					
(BAL)	(1)	390.06	1.61		(1)	4.12	0.01		1	1310.30	8.26	p= 0.065
(CO)	(1)	217.56	0.90		(1)	254.70	0.38					
(CO x BAL)	(1)	85.56	0.35		(1)	538.70	0.80					
Error	6	240.89			6	675.20			3	158.61		
Total	15				15				7			

ANOVA 8

Task: Standard Deviation Headway (Normal Vision)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	132.39	3.29	p = 0.1	3	32.43	1.04		3	18.62	0.35	
Day	3	37.18	0.92		3	11.86	0.38					
Level	3	38.06	0.94		3	2.94	0.09					
(BAL)	(1)	65.20	1.[illegible]		(1)	5.42	0.17		1	0.05	0.00	
(CO)	(1)	43.69	1.09		(1)	0.40	0.01					
(CO x BAL)	(1)	5.17	0.12		(1)	3.00	0.09					
Error	6	40.15			6	30.99			3	51.91		
Total	15				15				7			

ANOVA 9

Task: Mean Headway in Feet (car following with voluntary occlusion)

Source	Phase 1				Phase 2				Phase 2			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	2436.42	8.84	$p < 0.025$	3	3194.8	52.5	$p \leq 0.001$	3	679.9	5.82	$p \leq 0.10$
Day	3	1293.75	4.69	$p < 0.10$	3	671.1	10.1	$p \leq 0.01$				
Level	3	68.11	0.24		3	1056.9	15.9	$p \leq 0.005$	1	191.9	1.64	
(BAL)	(1)	0.27	0.00		(1)	1888.3	28.4	$p < 0.002$				
(CO)	(1)	174.90	0.63		(1)	1210.7	18.2	$p < 0.005$				
(CO x BAL)	(1)	35.70	0.12		(1)	71.57	1.08					
Error	6	275.51			6	66.54			3	116.69		
Total	15				15				7			

ANOVA 10

Task: Standard Deviation of Headway (Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	25.68	0.71		3	28.88	0.87		3	5.06	0.11	
Day	3	51.98	1.43		3	1.49	0.04					
Level	3	60.04	1.66		3	5.98	0.18		1	0.91	0.02	
(BAL)	(1)	110.77	3.07		(1)	0.10	0.00					
(CO)	(1)	26.76	0.74		(1)	0.15	0.00					
(CO x BAL)	(1)	42.57	1.18		(1)	17.71	0.53					
Error	6	36.06			6	33.05			3	43.49		
Total	15				15				7			

ANOVA 11

Task: Mean Open Time (seconds). Open Road--Voluntary Occlusion

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0.228	5.43	$p < 0.05$	3	0.1467	4.22	$p < 0.1$	3	0.829	9.03	$p < 0.1$
Day	3	0.016	0.39		3	0.0265	0.76					
Level	3	0.044	1.06		3	0.0102	0.29		1	0.293	3.20	
(BAL)	(1)	0.033	0.79		(1)	0.0001	0.002					
(CO)	(1)	0.095	2.26		(1)	0.0149	0.43					
(CO x BAL)	(1)	0.006	0.142		(1)	0.0156	0.45					
Error	6	0.042			6	0.0347			3	00.92		
Total	15				15				7			

ANOVA 12

Task: Standard Deviation of Open Times (Open Road--Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0.050	0.19		3	0.0254	13.74	$p < 0.005$	3	0.507	5.01	
Day	3	0.260	0.99		3	0.01227	6.64	$p < 0.025$				
Level	3	0.527	2.01		3	0.00156	2.47		1	0.375	3.70	
(BAL)	(1)	0.602	2.30		(1)	0.00391	2.11					
(CO)	(1)	0.589	2.25		(1)	0.00141	0.76					
(CO x BAL)	(1)	0.361	1.49		(1)	0.00837	4.53	$p < 0.10$				
Error	6	0.261			6	.00185			3	0.101		
Total	15				15				7			

ANOVA 13

Task: Mean Closed Time (seconds) (Open Road--Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0.143	1.79		3	0.670	5.60	$p < 0.05$	3	3.482	14.67	$p < 0.05$
Day	3	0.580	7.25	$p < 0.025$	3	0.020	0.17					
Level	3	0.715	9.33	$p < 0.025$	3	0.201	1.71		1	2.837	11.95	$p < 0.05$
(BAL)	(1)	0.451	5.65	$p = 0.05$	(1)	0.3906	3.26					
(CO)	(1)	1.051	13.16	$p < 0.01$	(1)	0.2194	1.83					
(CO x BAL)	(1)	0.733	9.18	$p < 0.02$	(1)	0.0026	0.02					
Error	6	0.079			6	0.1197			3	0.237		
Total	15				15				7			

ANOVA 14

Task: Standard Deviation of Closed Times (Open Road Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0.374	0.62		3	0.1765	3.48		3	0.374	21.38	$p < 0.025$
Day	3	2.158	3.62	$p < 0.10$	3	0.0493	0.97					
Level	3	1.473	2.47		3	0.0497	0.98		1	0.110	6.30	$p < 0.1$
(BAL)	(1)	0.862	1.44		(1)	0.1209	2.39					
(CO)	(1)	2.566	4.29	$p = .08$	(1)	0.0172	0.34					
(CO x BAL)	(1)	0.991	1.66		(1)	0.0109	0.31					
Error	6	0.596			6	.0507			3	0.017		
Total	15				15				7			

ANOVA 15

Task: Percent of Total Time Closed (Open Road)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	156.81	5.80	$p < 0.05$	3	159.24	3.93		3	63.42	3.06	
Day	3	25.59	0.95		3	11.20	0.28					
Level	3	1.42	0.05		3	9.69	0.24		1	9.31	0.45	
(BAL)	(1)	0.00	0.00		(1)	15.86	0.39					
(CO)	(1)	2.12	0.07		(1)	1.37	0.03					
(CO x BAL)	(1)	2.16	0.08		(1)	11.85	0.29					
Error	6	26.66			6	40.55			3	20.73		
Total	15				15				7			

ANOVA 16

Task: Mean Open Time-Seconds (Car Following--Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0.466	8.48	$p < 0.025$	3	0.1187	6.69	$p < 0.025$	3	0.520	12.30	$p < 0.05$
Day	3	0.027	0.49		3	0.0147	0.83					
Level	3	0.004	0.08		3	0.0222	1.25		1	0.121	2.87	
(BAL)	(1)	0.006	0.11		(1)	0.219	1.24					
(CO)	(1)	0.003	0.05		(1)	0.0066	0.37					
(CO x BAL)	(1)	0.004	0.77		(1)	0.0380	2.14					
Error	6	0.055			6	0.0177			3	0.042		
Total	15				15				7			

ANOVA 17

Task: Standard Deviation of Open Time (Car Following - Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0,185	5,95	p< 0,05	3	0,0087	0,82		3	0,2119	50,66	p< 0,005
Day	3	0,072	2,31		3	0,0109	1,03					
Level	3	0,0021	0,07		3	0,0680	0,64		1	0,0003	0,07	
(BAL)	(1)	0,0037	0,12		(1)	0,0030	0,28					
(CO)	(1)	0,0002	0,00		(1)	0,0014	0,14					
(CO x BAL)	(1)	0,0033	0,10		(1)	0,0160	1,50					
Error	6	0,0310			6	0,0106			3	0,0012		
Total	15				15				7			

ANOVA 18

Task: Mean Closed Time (Seconds) (Car Following - Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	1,480	7,87	p< 0,025	3	1,470	14,31	p< 0,005	3	1,616	7,64	p< 0,1
Day	3	0,231	1,22		3	0,134	1,30					
Level	3	0,211	1,12		3	0,199	1,94		1	0,012	0,06	
(BAL)	(1)	0,000	0,00		(1)	0,189	1,84					
(CO)	(1)	0,550	2,92		(1)	0,409	3,98	p: 0,0914				
(CO x BAL)	(1)	0,084	0,45		(1)	0,001	0,01					
Error	6	0,188			6	0,103			3	0,211		
Total	15				15				7			

ANOVA 19

Task: Standard Deviation Closed Time (Car Following - Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	0,7072	18,61	p< 0,005	3	1,584	1,70		3	0,232	5,29	
Day	3	0,0886	2,33		3	0,949	1,02					
Level	3	0,0349	0,92		3	0,657	0,71		1	0,030	0,68	
(BAL)	(1)	0,0885	2,32		(1)	0,316	0,34					
(CO)	(1)	0,0070	0,18		(1)	1,294	1,39					
(CO x BAL)	(1)	0,0094	0,24		(1)	0,363	0,39					
Error	6	0,038			6	0,931			3	0,044		
Total	15				15				7			

ANOVA 20

Task: Percent of Total Time Closed (Car Following - Voluntary Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	530,83	10,05	p< 0,01	3	307,82	60,05	p< 0,005	3	45,20	1,05	
Day	3	67,52	1,27		3	1,79	0,35					
Level	3	42,08	0,79		3	16,73	3,26		1	23,77	0,55	
(BAL)	(1)	2,56	0,04		(1)	0,01	0,002					
(CO)	(1)	95,79	1,81		(1)	3,97	0,77					
(CO x BAL)	(1)	27,90	0,52		(1)	46,21	9,01	p< 0,025				
Error	6	52,80			6	5,12			3	42,83		
Total	15				15				7			

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ANOVA 21

Task: Perceptual Uncertainty (Open Road Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	60.12	5.14	p < 0.025	3	68.37	8.80	p ≤ 0.025	3	179.26	9.29	p ≤ 0.05
Day	3	2.66	0.27		3	6.56	0.84					
Level	3	5.90	0.60		3	1.58	0.20					
(BAL)	(1)	3.52	0.36		(1)	3.62	0.47		1	52.58	2.73	
(CO)	(1)	11.15	1.45		(1)	[illegible]	0.03					
(CO x BAL)	(1)	0.17	0.01		(1)	0.89	0.11					
Error	6	0.74			6	7.77			3	19.30		
Total	15				15				7			

ANOVA 22

Task: Perceptual Uncertainty (Car Following - Occlusion)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	130.24	5.18	p < 0.05	3	42.90	13.31	p < 0.005	3	138.99	6.26	p < 0.1
Day	3	15.48	0.61		3	2.20	0.68					
Level	3	3.99	0.16		3	5.26	1.63					
(BAL)	(1)	0.098	0.001		(1)	4.42	1.37		1	48.31	2.18	
(CO)	(1)	1.89	0.07		(1)	0.52	0.16					
(CO x BAL)	(1)	10.08	0.40		(1)	10.84	3.38					
Error	6	25.12			6	3.22			3	22.20		
Total	15				15				7			

ANOVA 23

Task: Mean Time in FE (Open Road - Object Code)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	3.625	15.654	p < 0.005	3	0.517	1.60		3	1.79	1.90	
Day	3	0.134	0.582		3	0.572	1.77					
Level	3	0.165	0.713		3	0.227	0.70					
(BAL)	(1)	0.024	0.11		(1)	0.082	0.26		1	3.08	3.25	
(CO)	(1)	0.067	0.29		(1)	0.558	1.73					
(CO x BAL)	(1)	0.403	1.74		(1)	0.040	0.12					
Error	6	0.231			5	0.322			3	0.95		
Total	15				14				7			

ANOVA 24

Task: Standard Deviation of Time in FE (Open Road - Object Code)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	2.906	40.23	p < 0.001	3	0.566	1.245		3	4.75	1.98	
Day	3	0.008	0.11		3	0.346	0.762					
Level	3	0.564	0.78		3	0.006	0.013					
(BAL)	(1)	0.099	1.37		(1)	0.011	0.023		1	7.95	3.31	
(CO)	(1)	0.007	0.09		(1)	0.006	0.013					
(CO x BAL)	(1)	0.062	0.86		(1)	0.001	0.001					
Error	6	0.072			5	0.454			3	2.40		
Total	15				14				7			

ANOVA 25

Task: Percent of Total Time in FE

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	680.58	4.18	p< 0.1	3	637.35	0.94		3	673.9	2.15	
Day	3	419.73	2.58		3	693.08	1.03					
Level	3	152.71	0.91		3	355.35	0.53		1	1256.8	4.00	
(BAL)	(1)	16.04	0.10		(1)	1055.09	1.56					
(CO)	(1)	403.61	2.48		(1)	7.89	0.01					
(CO x BAL)	(1)	38.50	0.21		(1)	3.09	0.004					
Error	6	162.69			6	674.30			3	313.8		
Total	15				14				7			

ANOVA 26

Task: Mean Time in LC Code (Car Following)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	6.679	3.77		3	32.81	9.62	p 0.025	3	1.03	0.41	
Day	3	0.399	0.22		3	3.60	1.05					
Level	3	2.617	1.47		3	3.52	1.03		1	14.63	5.74	p< 0.1
(BAL)	(1)	1.991	1.12		(1)	0.33	0.10					
(CO)	(1)	5.745	3.24	p 0.1	(1)	3.91	1.14					
(CO x BAL)	(1)	0.113	0.06		(1)	6.34	1.86					
Error	6	1.772			6	3.41			3	2.55		
Total	15				15				7			

ANOVA 27

Task: Standard Deviation of Time in LC Code (Car Following)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	2.54	1.61		3	10.25	5.86	p< 0.05	3	0.145	0.19	
Day	3	1.91	1.21		3	0.55	0.31					
Level	3	2.38	1.51		3	2.92	1.67		1	1.190	1.56	
(BAL)	(1)	0.92	0.58		(1)	3.83	2.19					
(CO)	(1)	5.29	3.35	p< 0.1	(1)	2.00	1.14					
(CO x BAL)	(1)	0.92	0.58		(1)	2.94	1.68					
Error	6	1.58			6	1.75			3	0.760		
Total	15				15				7			

ANOVA 28

Task: Percent of Total Time in LC Code (Car Following)

Source	Phase 1				Phase 2				Phase 3			
	d. f.	Ms	F	p	d. f.	Ms	F	p	d. f.	Ms	F	p
Subject	3	682.70	3.63	p< 0.1	3	120.44	2.42		3	35.91	0.43	
Day	3	4.78	0.03		3	7.04	0.14					
Level	3	167.42	0.89		3	51.85	1.01		1	73.69	0.81	
(BAL)	(1)	19.74	0.10		(1)	23.76	0.48					
(CO)	(1)	473.39	2.51		(1)	32.09	0.65					
(CO x BAL)	(1)	9.14	0.05		(1)	99.70	2.00					
Error	6	188.24			6	49.74			3	90.84		
Total	15				15				7			

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ANOVA 29

Task: T_{used} (Sign Reading)

Source	Phase 1				Phase 2				Phase 3			
	d.f.	Ms	F	p	d.f.	Ms	F	p	d.f.	Ms	F	p
Subject	3	63.34	8.46	$p < 0.025$	3	235.81	6.35	$p < 0.05$	3	233.48	3.37	
Day	3	43.90	5.86	$p < 0.05$	3	16.44	0.44					
Level	3	56.55	7.56	$p < 0.025$	3	73.31	1.97		1	3.67	0.05	
(BAL)	(1)	4.45	0.59		(1)	172.13	4.63	p 0.073				
(CO)	(1)	0.62	0.08		(1)	33.75	0.90					
(CO x BAL)	(1)	164.60	21.98	p 0.0039	(1)	11.06	0.37					
Error	6	7.48			6	37.13			3	69.28		
Total	15				15				7			

ANOVA 30

Task: T_f (Sign Reading)

Source	Phase 1				Phase 2				Phase 3			
	d.f.	Ms	F	p	d.f.	Ms	F	p	d.f.	Ms	F	p
Subject	3	35.00	0.55		3	28.61	0.26		3	277.54	8.21	$p < 0.10$
Day	3	22.30	0.35		3	103.67	0.96					
Level	3	41.21	0.65		3	46.03	0.42		1	0.55	0.01	
(BAL)	(1)	2.16	0.03		(1)	110.98	1.03					
(CO)	(1)	103.83	1.65		(1)	5.54	0.05					
(CO x BAL)	(1)	17.64	0.28		(1)	21.57	0.20					
Error	6	62.56			6	107.46			3	33.75		
Total	15				15				7			

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